This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

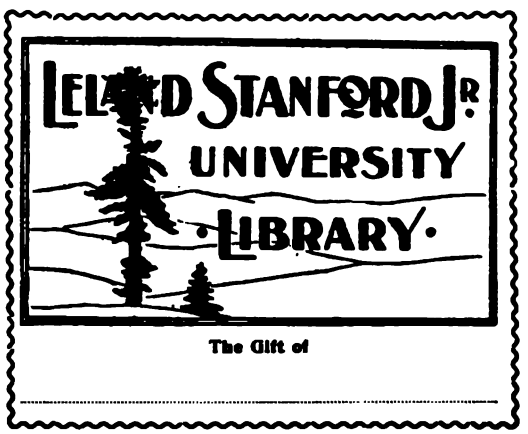
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

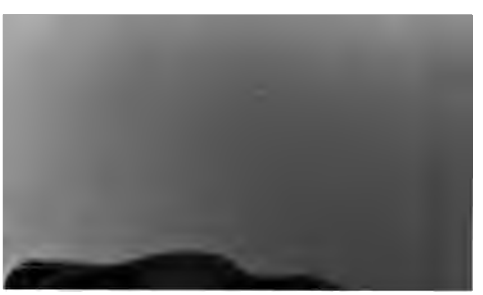
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

Stanford University Libraries


LELAND STANFORD JR.
UNIVERSITY
LIBRARY
The Gift of



STANFORD UNIVERSITY
LIBRARIES

TRANSACTIONS

OF THE

Engineering Library
HISTORICAL COLLECTION

AMERICAN SOCIETY

OF

MECHANICAL ENGINEERS.

VOL. XXI.

XLTH MEETING, NEW YORK CITY, 1899.
XLIST MEETING, CINCINNATI, OHIO, 1900.

NEW YORK CITY:
PUBLISHED BY THE SOCIETY,
FROM THE LIBRARY BUILDING,
NO. 12 WEST 31ST STREET.
1900.

LIBRARY OF THE
LELAND STANFORD JUNIOR UNIVERSITY.

Q.47269
A.6816
DEC 17 1900

Copyright, 1900,
BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

Press of J. J. Little & Co.
Astor Place, New York.

OFFICERS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

1899–1900,

FORMING THE STATUTORY COUNCIL.

PRESIDENT.

CHARLES H. MORGAN.....Worcester, Mass.

VICE-PRESIDENTS.

E. D. MEIER.....St. Louis, Mo.
GEORGE R. STETSON.....New Bedford, Mass.
B. H. WARREN.....Pittsburg, Pa.
Terms expire at Annual Meeting of 1900.

JESSE M. SMITH.....New York, N. Y.
STEVENSON TAYLOR.....Hoboken, N. J.
DAVID TOWNSEND.....Philadelphia, Pa.
Terms expire at Annual Meeting of 1901.

MANAGERS.

GEO. RICHMOND.....New York, N. Y.
JAS. B. STANWOOD.....Cincinnati, Ohio.
HENRY H. SUPLEE.....New York, N. Y.
Terms expire at Annual Meeting of 1900.

EDGAR C. FELTON.....Harrisburg, Pa.
A. M. GOODALE.....Waltham, Mass.
R. H. SOULE.....Chicago, Ill.
Terms expire at Annual Meeting of 1901.

FRANCIS H. BOYER.....Somerville, Mass.
JOHN A. BRASHEAR.....Allegheny, Pa.
ALFRED H. RAYNAL.....Washington, D. C.
Terms expire at Annual Meeting of 1902.

TREASURER.

WM. H. WILEY.....No. 43–45 East 19th St., New York, N. Y.

SECRETARY.

PROF. F. R. HUTTON.....No. 12 West 31st St., New York, N. Y.

HONORARY COUNCILLORS.

Past Presidents of the Society.

R. H. THURSTON	1880—1882	Ithaca, N. Y.
E. D. LEAVITT	1882—1883	Cambridgeport, Mass.
JOHN E. SWEET	1883—1884	Syracuse, N. Y.
COLEMAN SELLERS	1885—1886	Philadelphia, Pa.
HORACE SEE	1887—1888	New York City.
HENRY R. TOWNE	1888—1889	Stamford, Conn.
OBERLIN SMITH	1889—1890	Bridgeton, N. J.
ROBERT W. HUNT	1890—1891	Chicago, Ill.
CHARLES H. LORING	1891—1892	Brooklyn, N. Y.
CHARLES E. BILLINGS*	1895	Hartford, Conn.
JOHN FRITZ	1895—1896	Bethlehem, Pa.
WORCESTER R. WARNER	1896—1897	Cleveland, Ohio.
CHARLES WALLACE HUNT	1897—1898	New York City.
GEORGE W. MELVILLE	1898—1899	Washington, D. C.

[NOTE.—The former Presidents of the Society are members of the Council for life or during their retention of active membership in the Society.]

* Unexpired term of E. F. C. Davis.

NOTE.

The considerable bulk of the annual volume of Transactions has induced the Publication Committee to direct the insertion of a summary of the Society membership in place of the complete list of members which was published in earlier volumes. The summary attaching to this issue is that which appears in the catalogue of the Society issued with corrections to July, 1900. Reference for the complete list should be made to the twenty-first catalogue issued on that date. The summary is as follows :

Foreign Countries.

	Membership.		Membership.
Africa (East)	1	Great Britain (England)	33
" (South)	2	" " (Scotland)	4
Australia	1	Holland	2
" (South)	1	India	1
" (West)	1	Japan	6
Belgium	2	Mexico	3
Canada	12	Norway	2
Central America	1	Russia	4
China	3	South America	5
Cuba	3	Sweden	5
France	11	Switzerland	1
Germany	9		

Total foreign membership.....118

United States.

	Membership.		Membership.
Alabama	2	Missouri	28
Alaska	2	Montana	8
Arkansas	2	Nebraska	3
California	27	Nevada	1
Colorado	21	New Hampshire	13
Connecticut	93	New Jersey	112
Delaware	8	New Mexico	1
District of Columbia	23	New York	557
Florida	1	North Carolina	3
Georgia	5	Ohio	136
Illinois	133	Oregon	1
Indiana	29	Pennsylvania	301
Iowa	6	Porto Rico	1
Kansas	2	Rhode Island	36
Kentucky	3	South Carolina	3
Louisiana	6	Tennessee	3
Maine	12	Texas	2
Maryland	26	Vermont	6
Massachusetts	191	Virginia	24
Michigan	58	Washington	4
Minnesota	10	West Virginia	5
Mississippi	1	Wisconsin	41

Total membership in the United States.....1,950

GEOGRAPHICAL SUMMARY.

Total foreign membership	113
Total membership in United States	1,950
Present address unknown	1
Total membership	2,064

SUMMARY OF MEMBERSHIP BY GRADES.

Honorary members	16
Members	1,477
Associates	139
Junior members	432
Total membership	2,064

RULES OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

ART. 1. The objects of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS are to promote the Arts and Sciences connected with Engineering and Mechanical Construction, by means of meetings for social intercourse and the reading and discussion of professional papers, and to circulate, by means of publication among its members, the information thus obtained.

ART. 2. All persons connected with engineering may be eligible for admission into the Society.

ART. 3. The Society shall consist of Honorary Members, Members, Associates, and Juniors.

ART. 4. Honorary Members, not exceeding twenty-five in number, may be elected. They must be persons of acknowledged professional eminence.

ART. 5. To be eligible as a Member, the candidate must be not less than thirty years of age, and must have been so connected with engineering as to be competent as a designer or as a constructor, or to take responsible charge of work in his department, or he must have served as a teacher of engineering for more than five years.

NOTE.—The Rules of the Society, adopted in 1880, were in force until 1884, when they received general revision by a careful committee, whose report, distributed by letter ballot, was adopted November 5, 1884. In December, 1894, a similar extensive revision was made under direction of the Council, and the present rules are those of 1894. They include the amendments made in 1889, 1891, 1893, and 1898, which were the only changes since the revision of 1884.

ART. 6. To be eligible as an Associate the candidate must be not less than twenty-six years of age, and must have the other qualifications of a member; or he shall have been so connected with engineering as to be competent to take charge of work, and to coöperate with engineers.

ART. 7. To be eligible as a Junior, the candidate must have had such engineering experience as will enable him to fill a responsible position, or he must be a graduate of an engineering school.

ART. 8. All Honorary Members, Members, and Associates shall be equally entitled to the privileges of membership. Juniors shall not be entitled to vote, nor to be officers of the Society.

ART. 9. Nominees for Honorary Membership must be proposed by at least five Members who are not officers of the Society. References shall not be required of a nominee for Honorary Membership, but the grounds upon which the application is made must be fully set forth in writing and signed by the proposers.

ART. 10. A candidate for admission to the Society, as a Member or as an Associate, must make an application on a form to be prepared by the Council, which shall contain a written statement giving a complete account of his engineering experience and an agreement that he will, if elected, conform to the laws, rules, and requirements of the Society. He must refer to at least five Members or Associates to whom he is personally known. A candidate for admission to the Society as a Junior must make an application on the same form, and refer to not less than three Members or Associates to whom he is personally known.

Applications for membership from engineers who are not resident in the United States and Canada, and who may be so situated as not to be personally known to five Members of the Society, as required in the foregoing paragraph, may be recommended for ballot by five Members of the Council, after sufficient evidence has been secured which shall show that in their opinion the applicant is worthy of admission to the grade which he seeks.

ART. 11. The referees for each candidate for admission to the Society shall be requested to make a confidential communication on a form to be prepared by the Council, setting forth in detail

such information, personally known by the referee, as shall enable the Council to arrive at a proper estimate of the eligibility of the candidate for admission to the Society. Such confidential communications shall be destroyed by the Secretary as soon as the vote has been officially declared.

ART. 12. All applications for membership must be presented to the Council, and this body shall consider each application, assigning to each, with the applicant's consent, the grade in the Society to which, in its opinion, his qualifications entitle him. The names of those candidates recommended for election by the Society shall be immediately printed on a ballot, and the ballot mailed at once by the Secretary to each voting member of the Society. Persons desiring to change their grade of membership from junior to associate or from associate to member shall make an application in the same manner and on the same form as that required for a new applicant.

ART. 13. A member entitled to vote may leave the name of any candidate on the ballot untouched to vote in favor of the admission of the candidate to the Society, or he may erase the name to vote against it. He shall enclose the ballot so approved by him in a sealed blank envelope, and enclose this envelope in a second envelope, on which he shall write his name, and mail the same to the Secretary of the Society. A ballot without such endorsement shall be rejected as defective. The rejection of a candidate by seven voters shall defeat his election.

ART. 14. The aforesaid envelopes containing the ballots shall be opened by the Council, at any meeting thereof, and the names of those elected shall be announced in the next meeting of the Society. The names of applicants not elected shall not be announced, nor recorded in the proceedings.

ART. 15. Endorsers of any applicant not elected may, within three months after such failure to be elected, lay before the Council written evidence that an error was then made. The Council may then, by a three-fourths vote, order another similar ballot by the Society, in which case thirteen negative votes shall be required to defeat the candidate.

ART. 16. Honorary members shall be elected by the unanimous vote of the Council, through a letter ballot, not less than sixty days subsequent to the proposal, a notice of which proposed election shall have been mailed at once by the Secretary to each member of the Council.

ART. 17. Each person elected, excepting honorary members, must subscribe to the Rules of the Society, and pay the initiation fee before he can receive a certificate entitling him to the rights and privileges of the Society, and to wear the emblem appropriate to his grade. If this payment is not made within six months of the election, the same shall be void, unless the time is extended by the Council. The emblems of each grade of membership shall be worn by those only who belong to that grade.

ART. 18. The initiation fee of a member or an associate shall be twenty-five dollars, and the annual dues shall be fifteen dollars, payable in advance. The initiation fee of a junior shall be fifteen dollars, and his annual dues ten dollars, payable in advance. A junior being promoted to any other grade of membership shall pay an additional initiation fee of ten dollars. Any member or associate may become a Life Member in the same grade, by the payment of two hundred dollars at one time, and shall not be liable thereafter to annual dues.

The Council shall have the power, for special reasons, by unanimous vote, through a letter ballot, to admit to life membership, without the payment of the sum above named, such person as for a long term of years has been a member or an associate, when such a procedure would in its judgment be for the best interests of the Society; *provided*, that notice of such action shall have been given at a previous meeting of the Council.

ART. 19. Any member of the Society in arrears may, at the discretion of the Council, be deprived of the publications of the Society, or, when in arrears for one year, he may be stricken from the list of members. Such person may be restored to the privileges of membership by the Council on payment of all arrears.

ART. 20. The affairs of the Society shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers, and a Treasurer, who shall also be the Trustees of the Society.

All past (ex) Presidents of the Society, while they retain their membership therein, shall be known as Honorary Councillors, and shall be entitled to receive notices of all meetings of the Council and may take part in any of its deliberations; they shall be entitled to vote upon all questions except such as affect the legal rights or obligations of the Society or its members.

ART. 21. The members of the Council shall be elected from among the members and associates of the Society at the annual meetings, and shall hold office as follows:

The President and the Treasurer for one year; and no person shall be eligible for immediate re-election as President who shall have held that office for two consecutive years; the Vice-Presidents for two years, and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected.

ART. 22. A Secretary, who shall be a member of the Society, shall be appointed for one year by a majority of the members of the Council at its first meeting after the annual election, or as soon thereafter as the votes of a majority of the members of the Council can be secured for a candidate. The Secretary may be removed by a vote of twelve members of the Council, at any time after one month's notice has been given him by a majority of its members to show cause why he should not be removed, and he has been heard to that effect. The Secretary may take part in any of the deliberations of the Council, but shall not have a vote therein. His salary shall be fixed for the time he is appointed by a majority vote of the Council.

ART. 23. At each annual meeting, a President, three Vice-Presidents, three Managers, and a Treasurer shall be elected, and the term of office of each shall continue until the end of the meeting at which their successors are elected.

ART. 24. The duties of all officers shall be such as usually pertain to their offices or may be delegated to them by the Council or by the Society. The Council may, in its discretion, require bonds to be given by the Treasurer.

ART. 25. The Council may, by vote of a majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings, or to perform the duties of his office. All such vacancies and those occurring by death or resignation shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *provided*, that the said appointment shall not render him ineligible at the next annual meeting.

ART. 26. Five members of the Council shall constitute a quorum. Members of the Council absent from a meeting may vote by letter upon subjects stated in the call for the meeting, said vote to be deposited with the Secretary.

ART. 27. The President on assuming office shall appoint a Finance Committee and a Publication Committee and a Library Committee of five members each. The appointment of two members of each Committee shall expire at the end of each year. The Secretary shall, *ex officio*, be a member of all three committees.

ART. 28. The Finance Committee shall have power to order all ordinary or current expenditures, and shall audit all bills therefor. No bill shall be paid except upon their audit. When special appropriations are ordered by the Society, they shall not take effect until they have been referred to the Council and Finance Committee in conference.

ART. 29. It shall be the duty of the Publication Committee to receive all papers contributed, and to decide upon which papers or parts of the same shall be presented at the professional meetings of the Society. They shall see that all editorial revisions of the proceedings, papers, discussions, and reports are made; and to decide what parts of the same shall be published in the proceedings of the Society. The Council may, at its discretion, revise any action of the Publication Committee.

ART. 30. It shall be the duty of the Library Committee to take charge of the collection of all material for the Library of the Society, and to supervise all regulations for its use.

ART. 31. At the regular meeting preceding the annual meeting a Nominating Committee of five members, not officers of the Society, shall be appointed, and this committee shall, at least thirty days before the annual meeting, send to the Secretary the names of nominees for the offices falling vacant under the rules. In addition to such regularly appointed committee, any other five members or associates, not in arrears, may constitute an independent Nominating Committee, and may present to the Secretary, at least thirty days before the annual meeting, all the names of such candidates as they may select. All the names of such independent nominees shall be placed upon the ballot list, with nothing to distinguish them from the nominees of the regular committee, and the Secretary shall at once mail the said list of names to each member and associate in the form of a letter ballot, it being understood that the assent of the nominees shall have been secured in all cases.

ART. 32. In the election of Vice-Presidents, each member and associate may cast as many votes as there are Vice-Presidents

to be elected. He may give all these votes to one candidate, or distribute them among more, as he chooses. Managers shall be voted for in the same way.

ART. 33. Any member or associate entitled to vote may vote by retaining or changing the names on said list, leaving names not exceeding in number the officers to be elected, and returning the list to the Secretary—such ballot enclosed in two envelopes, the inner one to be blank and the outer one to be endorsed by the voter. No member or associate in arrears since the last annual meeting shall be allowed to vote until said arrears shall have been paid.

ART. 34. The said blank envelopes shall be opened by tellers at the annual meeting, and the person who shall have received the greatest number of votes for the several offices shall be declared elected.

MEETINGS.

ART. 35. The annual meeting of the Society shall be held on the first Tuesday in December of each year, in the City of New York, unless otherwise ordered, at which a report of proceedings and an abstract of the accounts shall be furnished by the Council. The Council may change the place of the annual meeting, and shall, in that case, give timely notice to members and associates.

ART. 36. Other regular meetings of the Society shall be held in each year at such time and place as the Council may appoint. At least thirty days' notice of all meetings shall be mailed by the Secretary to members, honorary members, associates, and juniors.

ART. 37. Special meetings may be called whenever the Council may see fit; and the Secretary shall call a special meeting at the written request of twenty or more members. The notices for special meetings shall state the business to be transacted, and no other shall be entertained.

ART. 38. Any member, honorary member, or associate, may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

ART. 39. Every question which shall come before the Society shall be decided, unless otherwise provided by these rules, by the votes of a majority of the members and associates present, provided there is a quorum.

ART. 40. At any regular meeting of the Society thirteen or more members and associates shall constitute a quorum.

ART. 41. Unless otherwise ordered, papers shall be read in the order in which their text is received by the Secretary. Before any paper appears in the *Transactions* of the Society, a copy of the paper shall be sent to the author, and, so far as possible, a copy of the reported discussion shall be sent to every member who took part in the same, with requests that attention shall be called to any errors therein.

ART. 42. The Society shall claim no exclusive copyright in papers read at its meetings, nor in reports of discussions, except in the matter of official publication with the Society's imprint, as its *Transactions*. The Secretary shall have sole possession of papers between the time of their acceptance by the Publication Committee and their reading, together with the drawings illustrating the same; and at the time of such reading, or as soon thereafter as practicable, he shall cause to be printed, with the authors' consent, copies of such papers, "subject to revision," with such illustrations as are needed for the *Transactions*, for distribution to the members and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest circulation possible, with the view of making the work of the Society known, encouraging mechanical progress, and extending the professional reputation of its members.

ART. 43. The author of each paper read before the Society shall be entitled to twelve copies, if printed, for his own use, and all members shall have the right to order any number of reprints of papers at a cost to cover paper and printing; *provided*, that said copies are not intended for sale.

ART. 44. The Society is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions, at its meetings; and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

ART. 45. These rules may be amended, at any annual meeting, by a two-thirds vote of the members present; *provided*, that written notice of the proposed amendment shall have been given at a previous meeting.

CONTENTS OF VOLUME XXI.

			PAGE
No. 826		Proceedings of the New York (XLth) Meeting	3
No. 827		Report of the Committee on Revision of Society Code of 1885, relative to a Standard Method of Conducting Steam-Boiler Trials	34
No. 828		Discussion on Report of Boiler Committee	112
No. 829	MELVILLE, GEO. W.	Engineering in the United States Navy. Its Personnel and Matériel	139
No. 830	RICE, ARTHUR L.	Compression and Liquefaction of Gases	156
No. 831	POOLE, HERMAN	Experiments on Using Gasoline Gas for Boiler Heating	172
No. 832	THURSTON, ROBT. H.	The Steam Engine at the End of the Nineteenth Century	181
No. 833	WAGNER, FRANK C.	Friction Tests of a Locomotive Slide Valve	242
No. 834	PEEK, GEO. M.	Pressure in Pipe Due to Stoppage of Flowing Liquid	255
No. 835	MCBRIDE, JAS.	A Broken Fly-wheel and how it was Repaired	263
No. 836	EDDY, HENRY T.	New Graphical Method of Constructing Entropy Temperature Diagram of a Gas or Oil Engine from its Indicator Card	275
No. 837	BENJAMIN, C. H.	Friction of Steam Packings	292
No. 838	KERR, C. V.	The Berthier Method of Coal Calorimetry	304
No. 839	FRITH, A. J.	A Note on Fly-wheel Design	317
No. 840	LAIRD, JNO. A.	Test of Two Ten-Million-Gallon Pumping Engines at the Baden Pumping Station, St. Louis Water Works, June, '99	327
No. 841	HARRIS, J. F. W.	Strength of Steel Balls	351
No. 842	KEEP, W. J.	Impact	369
No. 843	ROBERTSON, C. H.	An Efficiency Test of a One Hundred and Twenty-five Horse-power Gas Engine	396
No. 844	STILLMAN, F. H.	High Hydrostatic Pressures and their Application to Compressing Liquids. A New Form of Pressure Gauge	439

ART. 40. At any regular meeting of the Society thirteen or more members and associates shall constitute a quorum.

ART. 41. Unless otherwise ordered, papers shall be read in the order in which their text is received by the Secretary. Before any paper appears in the *Transactions* of the Society, a copy of the paper shall be sent to the author, and, so far as possible, a copy of the reported discussion shall be sent to every member who took part in the same, with requests that attention shall be called to any errors therein.

ART. 42. The Society shall claim no exclusive copyright in papers read at its meetings, nor in reports of discussions, except in the matter of official publication with the Society's imprint, as its *Transactions*. The Secretary shall have sole possession of papers between the time of their acceptance by the Publication Committee and their reading, together with the drawings illustrating the same; and at the time of such reading, or as soon thereafter as practicable, he shall cause to be printed, with the authors' consent, copies of such papers, "subject to revision," with such illustrations as are needed for the *Transactions*, for distribution to the members and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest circulation possible, with the view of making the work of the Society known, encouraging mechanical progress, and extending the professional reputation of its members.

ART. 43. The author of each paper read before the Society shall be entitled to twelve copies, if printed, for his own use, and all members shall have the right to order any number of reprints of papers at a cost to cover paper and printing; *provided*, that said copies are not intended for sale.

ART. 44. The Society is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions, at its meetings; and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

ART. 45. These rules may be amended, at any annual meeting, by a two-thirds vote of the members present; *provided*, that written notice of the proposed amendment shall have been given at a previous meeting.

CONTENTS OF VOLUME XXI.

			PAGE
No. 826		Proceedings of the New York (XLth) Meeting	3
No. 827		Report of the Committee on Revision of Society Code of 1885, relative to a Standard Method of Conducting Steam-Boiler Trials	34
No. 828		Discussion on Report of Boiler Committee	112
No. 829	MELVILLE, GEO. W.	Engineering in the United States Navy. Its Personnel and Matériel	139
No. 830	RICE, ARTHUR L.	Compression and Liquefaction of Gases	156
No. 831	POOLE, HERMAN	Experiments on Using Gasoline Gas for Boiler Heating	172
No. 832	THURSTON, ROBT. H.	The Steam Engine at the End of the Nineteenth Century	181
No. 833	WAGNER, FRANK C.	Friction Tests of a Locomotive Slide Valve	242
No. 834	PEEK, GEO. M.	Pressure in Pipe Due to Stoppage of Flowing Liquid	255
No. 835	MCBRIDE, JAS.	A Broken Fly-wheel and how it was Repaired	262
No. 836	EDDY, HENRY T.	New Graphical Method of Constructing Entropy Temperature Diagram of a Gas or Oil Engine from its Indicator Card	275
No. 837	BENJAMIN, C. H.	Friction of Steam Packings	292
No. 838	KERR, C. V.	The Berthier Method of Coal Calorimetry	304
No. 839	FRITH, A. J.	A Note on Fly-wheel Design	317
No. 840	LAIRD, JNO. A.	Test of Two Ten-Million-Gallon Pumping Engines at the Baden Pumping Station, St. Louis Water Works, June, '99	327
No. 841	HARRIS, J. F. W.	Strength of Steel Balls	351
No. 842	KEEP, W. J.	Impact	369
No. 843	ROBERTSON, C. H.	An Efficiency Test of a One Hundred and Twenty-five Horse-power Gas Engine	396
No. 844	STILLMAN, F. H.	High Hydrostatic Pressures and their Application to Compressing Liquids. A New Form of Pressure Gauge	439

		PAGE
No. 845	KERR, WALTER C. — The Mechanical Equipment of the New South Station, Boston, Mass.	451
No. 846	CHAMBERLAIN, P. M. — A Metal Dynamograph	578
No. 847	CHAMBERLAIN, P. M. — A Curved Glass Blue-print Machine	586
No. 848	ROCKWOOD, GEO. I. — On the Value of a Horse-power	590
No. 849	WHITE, MAUNSEL, and TAYLOR, F. W. — Colors of Heated Steel Corresponding to Different Degrees of Temperature	627
No. 850	HIGGINS, M. P. — Education of Machinists, Foremen, and Mechanical Engineers	646
No. 851	Discussion of Education of Machinists, Foremen, and Mechanical Engineers	685
No. 852	Proceedings of the Cincinnati (XLIst) Meeting	771
No. 853	FOSTER, E. H. — Pumping-engine Test with Superheated Steam	788
No. 854	GOSS, W. F. M. — Test of the Snow Pumping Engine at the Riverside Station of the Indianapolis Water Company	793
No. 855	GUEST, J. A. — On the Design of Speed Cones. A New Formula	832
No. 856	HERSCHMANN, ARTHUR. — The Automobile Wagon for Heavy Duty	844
No. 857	GOLDSMITH, N. O. — Water-softening Plant at the Lorain Steel Company's Blast Furnace.	874
No. 858	THURSTON, R. H. — Reheaters in Multiple-cylinder Engines	893
No. 859	ALDRICH, W. S. — Systems and Efficiency of Electric Transmission in Factories and Mills	912
No. 860	YARYAN, H. T. — Hot-water Heating from a Central Station	937
No. 861	MAGRUDER, WM. T. — The Gas-engine Hot Tube as an Ignition-timing Device	961
No. 862	BALL, B. C. — Cylinder Proportions for Compound Engines	1002
No. 863	COOLEY, M. E., WAGNER, F. C., and ALLEN, J. R. — Test of a Fifteen-million High-duty Pumping Engine at Grand Rapids, Mich.	1018
No. 864	HIGGINS, M. P. — Education of Machinists, Foremen, and Mechanical Engineers	1114
No. 865	Topical Discussions and Notes of Experience	1154
No. 866	Memorials	1158

LIST OF ILLUSTRATIONS.

FIG.		PAGE
1.	Barrus, coal calorimeter	66
2.	Barrus, steam calorimeter	73
3.	Barrus, draught gauge	88
4.	Kent, gasometer draught gauge	89
5.	Hoadley, apparatus for sampling flue gases	92
6.	Ringelmann, smoke chart	98
7.	Boiler-test graphical log	104
8.	Jacobus, apparatus to determine moisture in horizontal pipe	107
9.	Eames, differential draught gauge	123
10.	Bryan, device for thermometer in flues	124
11.	Bryan, inclined draught gauge	124
12–14.	Apparatus for liquefying gases	157
15.	Pictet, cascade system for liquefying gases	160
16.	Linde, apparatus for liquefying air	163
17.	Dewar, apparatus for liquefying air	164
18.	Tripler, apparatus for liquefying air	165
19.	Bates, flange chart	30
20.	Thurston, quadruple-expansion engine	180
21.	" temperature entropy diagram	193
22.	" pressure of volume diagram	194
23.	" diagram of progress of steam-engine efficiency	198
24.	" performance of best types of engines	201
25.	" elevation of Nordberg engine	204
26.	" pumps and heater system of Nordberg engine	206
27.	" " " " " " "	208
28.	" detail of feed pump, Nordberg engine	210
29.	" detail of piping, Nordberg engine	213
30.	" Sankey, diagram, Nordberg engine	216
31.	" diagram of engine efficiency	222
32.	" elevations of Nordberg engine	Faces 222
33.	" sections and plans, Nordberg engine	222
34.	" pumps of Nordberg engine	Faces 222
35.	" combined diagrams, Nordberg engine, with heaters	" 222
36.	" " " " " without heaters	" 222
37.	Stanwood, temperature entropy diagram, Nordberg engine	228
38.	Diagrams of friction test, locomotive slide valve	245
38*a*.	Smart, disc., tests of the locomotive slide valve	247
39, 40, and 41.	McBride, repair of broken fly-wheel	263
42–47.	" " " "	264
48–50.	" " " "	266
51–53.	" " " "	267
54–55.	" " " "	268
56.	" " " "	265

FIG.		PAGE
189.	Kerr describes Southern Station, Boston Terminal Company	519
190.	" " " " " " "	521
191.	" " " " " " "	522
192.	" " " " " " "	523
193.	" " " " " " "	525
194.	" " " " " " "	527
195.	" " " " " " "	529
196.	" " " " " " "	531
197.	" " " " " " "	533
198.	" " " " " " "	537
199.	" " " " " " "	539
200.	" " " " " " "	541
201.	" " " " " " "	543
202.	" " " " " " "	545
203.	" " " " " " "	546
204.	" " " " " " "	547
205.	" " " " " " "	548
206.	" " " " " " "	551
207.	" " " " " " "	553
208.	" " " " " " "	556
209.	" " " " " " "	559
210.	" " " " " " "	560
211.	" " " " " " "	562
212.	" " " " " " "	563
213.	" " " " " " "	564
214.	Chamberlain, metal dynamograph	579
215.	" " "	580
216.	" " "	581
217.	" " "	582
218, 219.	" " "	583
220, 221.	Chamberlain, blue-print machine	587
222, 223.	" " "	588
224.	" " "	589
225.	Foster, engine test with superheated steam	790
226.	Goss, tests of Snow pumping engine	796
227.	" " " " "	797
228.	" " " " "	Faces 798
229.	" " " " "	" 798
230.	" " " " "	" 798
231.	" " " " "	" 798
232.	" " " " "	800
233.	" " " " "	Faces 800
234.	" " " " "	801
235.	" " " " "	803
236.	" " " " "	804
237.	" " " " "	805
238.	" " " " "	819
239–242.	Heisler, disc., test of Snow pumping engine	826
243.	Heisler, disc., test of Snow pumping engine	827
244.	" " " " " "	828

FIG.		PAGE
137.	Robertson, test of gas engine	408
138.	" " " "	409
139.	" " " "	411
140.	" " " "	414
141.	" " " "	415
142.	" " " "	417
143.	" " " "	418
144.	" " " "	421
145.	" " " "	423
146.	Ruud, disc., Robertson test of gas engine	429
147.	Stillman-Hite apparatus for high fluid pressure	440
148.	" " " " "	441
149.	" " " " "	442
150.	" " " " "	445
151.	Jacobus, disc., packings for high pressure	448
152.	Kerr describes Southern Station, Boston Terminal Company	452
153.	" " " " " " "	Faces 452
154.	" " " " " " "	454
155.	" " " " " " "	460
156.	" " " " " " "	Faces 462
157.	" " " " " " "	464
158.	" " " " " " "	465
159.	" " " " " " "	468
160.	" " " " " " "	Faces. 468
161.	" " " " " " "	470
162.	" " " " " " "	472
163.	" " " " " " "	474
164.	" " " " " " "	475
165.	" " " " " " "	476
166.	" " " " " " "	478
167–8–9.	Kerr describes Southern Station, Boston Terminal Company	Faces 479
170.	" " " " " " "	480
171.	" " " " " " "	482
172.	" " " " " " "	488
173.	" " " " " " "	490
174.	" " " " " " "	492
175.	" " " " " " "	494
176.	" " " " " " "	495
177.	" " " " " " "	496
178.	" " " " " " "	498
179.	" " " " " " "	Faces 498
180.	" " " " " " "	503
181.	" " " " " " "	505
182.	" " " " " " "	508
183.	" " " " " " "	509
184.	" " " " " " "	510
185.	" " " " " " "	511
186.	" " " " " " "	514
187.	" " " " " " "	516
188.	" " " " " " "	516

FIG. PAGE
345. Ball, diagram for proportioning compound engines.....1014
346. " " " " " ..... .1015
347. " " " " " 1016
348. " " " " " 1017
349. Cooley, pumping-engine test, general 1028
350. " " " " " 1034
351–356. Cooley, pumping-engine test, combined cards..... 1060–1065
357–359. " " " " steam cards 1072–1074
360–366. " " " " water cards 1094–1099
367–372. " " " " " " 1104–1109

FIG. PAGE
245, 246. Guest, diagram for speed cones 833
247. Herschmann, automobile for heavy duty ....Faces 845
248. " " wagon, storage shed for..... " 857
249, 250. Herschmann, automobile wagon, diagram for tests..... 862
251. Herschmann, automobile wagon, boiler..... 863
252. " " " " 864
253, 254. Herschmann, automobile wagon, boiler .....Faces 863
255. Herschmann, automobile wagon, detail..... " 863
256. " " " ..... " 863
257. " " " Maxwell disk driving gear 876
258. " " " Chamberlain box gear 869
259. Goldsmith, Lorain water-softening plant, exterior 876
260. " " " " interior 878
261. Reheater for multiple-cylinder engines, Rockwood's design 909
262. " " " " " 910
263. " " " " " 911
264. Aldrich, efficiency of electrical shafting compared with 916
265. Aldrich, efficiency of electrical transmission, D. C. motors 917
266. " " " " with motors of different sizes..... 918
267. " " " " induction motor..... 923
268. " " " " synchronous motor 926
269. " " " " comparative curves 927
270. Yaryan, hot-water heating system..... 939
271. " " " " " block plan..... 941
272. " " " " Floyd Street Station 942
273. " " " " insulation..... 943
274. " " " " grease track..... 945
275. Magruder, gas-engine mixing chamber 965
276. " " " " " 966
277–279. Magruder, gas engine, diagrams 969
280–282. " " " " 970
283–285. " " " " 971
286–288. " " " " 972
289–291. " " " " 973
292–294. " " " " 975
295–297. " " " " 976
298–300. " " " " 977
301–303. " " " " 978
304–306. " " " " 980
307–309. " " " " 981
310–312. " " " " 982
313–315. " " " " 984
316–324. " " " " 985–987
325–330. " " " " 989–999
331–339. " " " " 991–993
340–341. " " " Emory discussion 999
342. Ball, diagram for proportioning compound engines.....1004
343. " " " " " 1007
344. " " " " " 1013

FIG. PAGE
345. Ball, diagram for proportioning compound engines.....1014
346. " " " " " 1015
347. " " " " " 1016
348. " " " " " 1017
349. Cooley, pumping-engine test, general 1028
350. " " " " " 1034
351-356. Cooley, pumping-engine test, combined cards..... 1060-1065
357-359. " " " " steam cards 1072-1074
360-366. " " " " water cards 1094-1099
367-372. " " " " " " 1104-1109

No. 826.

PROCEEDINGS

OF THE

NEW YORK MEETING

(XLth)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

December 5th to December 8th, 1899.

THE twentieth annual meeting of the Society was also its fortieth convention, and was held in New York City, beginning Tuesday, December 5th, and adjourning on Friday, December 8th.

Sessions for papers were convened in the auditorium of the Society house, at No. 12 West Thirty-first Street, but the parlors and library above were filled with guests and visitors, even at the time that the discussions of professional papers were in progress.

The opening session was set down for Tuesday evening, at nine o'clock, but members began to gather for the social opportunities of a preceding reunion at an early hour, and it was manifest that the meeting was to be numerically surprising, even at the close of the first session.

The President of the Society, Rear-Admiral George W. Melville, called the opening meeting to order promptly at nine o'clock, and, after appointing Messrs. Ball, Van Derhoef, and Lewis to act as tellers, under Article 34 of the Rules, for the counting of officers' ballots, proceeded to deliver his presiden-

No. 826.

PROCEEDINGS

OF THE

NEW YORK MEETING

(XLth)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

December 5th to December 8th, 1899.

THE twentieth annual meeting of the Society was also its fortieth convention, and was held in New York City, beginning Tuesday, December 5th, and adjourning on Friday, December 8th.

Sessions for papers were convened in the auditorium of the Society house, at No. 12 West Thirty-first Street, but the parlors and library above were filled with guests and visitors, even at the time that the discussions of professional papers were in progress.

The opening session was set down for Tuesday evening, at nine o'clock, but members began to gather for the social opportunities of a preceding reunion at an early hour, and it was manifest that the meeting was to be numerically surprising, even at the close of the first session.

The President of the Society, Rear-Admiral George W. Melville, called the opening meeting to order promptly at nine o'clock, and, after appointing Messrs. Ball, Van Derhoef, and Lewis to act as tellers, under Article 34 of the Rules, for the counting of officers' ballots, proceeded to deliver his presiden-

tial address, which he had given the title of "Engineering in the United States Navy: Its Personnel and Matériel." At its close, announcements in connection with the meeting were read by the Secretary, and the members adjourned to a light luncheon in the supper room. The attention of the members was directed to a most interesting water-color, or sepia drawing, which had been presented to the Society by Miss Cornelia J. Carll. It bore in the corner the autograph signature of Robert Fulton, and represented his design for the transfer of a canal boat by means of an aqueduct across a ravine. The propelling energy for the boats was derived from the descent of water in a series of buckets upon an endless chain. Miss Carll had announced the drawing as authentic, and it had been carefully framed and was now presented to the Society.

Second Day. Wednesday, December 6th.

The second, or business, session of the annual meeting was called to order at ten o'clock. In calling the attention of the membership to the phenomenal registration, as indicated by the following list of members present at the meeting, it is interesting to add that the social atmosphere of the meeting, in view of its size, was equally noteworthy. The plan was continued, which has prevailed for several years, of having each convention button-badge bear a number corresponding to the line on the Secretary's register upon which the member had written his name. Printed lists, transcripts from this register, giving the name and corresponding number, were issued at short intervals during the meeting, and served to render easy the approaches of members for the renewal of old acquaintances and for the making of new friendships. The register showed the total number in attendance to be 706.

The names of the members in attendance are given in the following list:

Ackerman, W. S.
Alberger, Louis R.
Alden, Geo. I.
Aller, A.
Almirall, J. A.
Almond, Thos. R.
Almy, Darwin.
Archer, E. R.
Ashworth, D.
Aue, Jos. E.
Bagg, S. F.
Bailey, W. H.
Baldwin, Stephen W.
Baldwin, Wm. J.
Ball, F. H.
Bang, Henry A.
Bardwell, A. F.
Barnaby, C. W.
Barnes, A. T.
Barney, J. M.
Barr, H. P.
Barrus, G. H.
Basford, G. M.
Batchelor, Chas.
Bates, E. C.
Bates, E. P.
Bauer, Chas. L.

Beach, G.
Benns, C. P.
Billings, C. E.
Binsse, H. B.
Bird, J. D.
Bird, W. W.
Black, Chas. S.
Blackburn, A. H.
Boerner, E. C.
Bole, Wm. A.
Bolton, R. P.
Bond, Geo. M.
Bonner, Wm. T.
Bowden, J. H.
Bowman, A. L.
Bowman, F. M.
Boyer, E. S.
Boyer, Francis H.
Bradley, W. H.
Bragg, C. A.
Braine, B. G.
Brashear, Jno. A.
Brinsmade, L. L.
Bristol, W. H.
Brooks, E. C.
Brooks, T. H.
Brown, Robt. S.
Bruck, H. T.
Bulkley, H. W.
Bullard, E. P.
Bull, G. H.
Burditt, Wm. F.
Burnham, H. A.
Burnham, Wm.
Cadwell, Wm. D.
Cary, Albert A.
Cash, A. W.
Cassier, Louis.
Cathcart, W. L.
Chadwick, Lee S.
Challen, Paul J.
Chamberlain, P. M.
Chandler, I. A.
Chapin, W. W.
Chase, Harvey S.
Cheney, W. L.
Childs, Eugene.
Christie, James.
Christie, W. W.
Churchill, W. W.
Clarke, Chas. L.
Clarke, Saml. J.
Close, R. T.
Cogswell, W. B.
Colby, A. L.
Cole, J. W.
Colvin, Fred. H.
Colwell, A. W.
Connell, J. A.
Cooley, M. E.
Corbett, C. H.
Coster, Edw. L.
Cowperthwait, A.
Craig, James.
Creelman, Frank.
Cremer, J. M.
Cullingsworth, G. R.
Cummings, O. P.
Darling, Edward A.
Darrin, D. H.
Davis, Daniel.
Deane, Chas. P.
Dean, F. W.
Derbyshire, Wm. H.
Deming, W. H.
DePuy, C. E.
Dinkel, Geo.
Earll, Chas. I.
Ekstrand, Chas.
Evans, Q. N.
Faber Du Faur, A.
Farwell, E. S.
Fellows, E. R.
Ferguson, Geo. R.
Finley, A. D.
Freeman, Jno. R.
Fladd, F. C.
Flint, B. P.
Forbes, W. D.
Foster, Chas. F.
Foster, E. H.
Fowler, Geo. L.
Francis, H. C.
French, L. G.
Frevert, H. F.
Frith, A. J.
Fritz, John.
Fry, Alfred Brooks.
Fulton, Geo. R.
Gantt, H. L.
Garfield, L. M.
Geoghegan, S. J.
Giles, C. E.
Gobeille, Jos. L.
Goetze, Fredk. A.
Gould, W. V.
Gower, Chas. A.
Granger, A. S.
Greenleaf, Geo. E.
Green, Saml. M.
Gregory, Wm.
Griffith, Jno.
Grimm, P. H.
Gulowsen, G. A.
Gwilliam, Geo. T.
Hague, Chas. A.
Haight, H. V.
Haines, H. S.
Hale, R. S.
Hall, Robt. E.
Halsey, F. A.
Hamilton, J. V.
Harding, A.
Harris, F. W. H.
Hartness, Jas.
Henderson, Alex.
Henderson, J. C.
Henning, G. C.
Herbert, F. D.
Hewlett, E. M.
Hibbard, H. D.
Higgins, M. P.
Hill, W. E.
Hillard, Chas. J.
Hillman, Gustave.
Hobart, J. C.
Hoffecker, W. L.
Holbrook, D. L.
Honiss, Wm. H.
Hoppes, J. J.
Horton, Jno. T.
Howe, Henry M.
Hoxie, W. D.
Hunt, Chas. W.
Hunt, Robt. W.
Hunt, W. F.
Huston, Chas. L.
Hutton, F. R.
Hyde, Chas. E.
Idell, F. E.

Jacobus, D. S.
Jefferies, E. A. W.
Jenkins, M. C.
Jenks, L. Howard.
Jenks, W. H.
Jennings, E. L.
Jewell, C. W.
Jordan, S. S.
Kafer, Jno. C.
Katte, E. B.
Keep, W. J.
Kent, Wm.
Kerr, W. C.
King, C. C.
King, W. Grant.
Kirchhoff, C.
Klein, J. S.
Knickerbacker, Jno.
Laforge, F. H.
Laidlaw, Walter.
Lanza, Gaetano.
Leonhard, T. S.
Lewis, D. J., Jr.
Lewis, Wilfred.
Libby, S. H.
Lieb, Jno. W., Jr.
Lodge, Wm.
Logan, Jno. D.
Longenecker, C. K.
Longstreth, Chas.
Loomis, F. J.
Lorenz, Wm. A.
Loring, Chas. H.
Low, F. R.
Loyd, Jno.
Lyall, Wm. L.
McBride, Jas.
McCallum, A. C.
McFarland, W. M.
McKean, R. A.
McKinney, R. C.
McLaren, M. N.
McMannis, Wm.
MacPherson, Jas. D.
Main, Chas. T.
Manning, Chas. H.
Marshall, Alfred.
Mason, D. A.
Mattes, W. F.
Matton, F. V.
Meatz, Jno. T.
Meier, E. D.
Melville, Geo. W.
Mesta, Geo.
Meyer, H. C., Jr.
Miller, F. J.
Miller, L. B.
Moeller, Franklin.
Monaghan, Wm. F.
Moore, D. G.
Moore, M. F.
Morehouse, W. S.
Morgan, Chas. H.
Morgan, Paul B.
Morison, Geo. S.
Mossberg, Frank.
Moulthrop, Leslie.
Muller, T. H.
Mumford, E. H.
Murray, Chas. R.
Nagle, A. F.
Nason, Carleton W.
Neff, E. H.
Newcomb, Chas. L.
Newhall, J. B.
Newton, C. E.
Nicoll, Chas. H.
Norris, H. M.
Norris, J. H.
Odell, W. H.
Olin, F. W.
Otis, Spencer.
Owens, R. B.
Parker, Chas. D.
Parks, E. H.
Parsons, F. W.
Parsons, H. deB.
Patterson, A. W., Jr.
Paul, J. W.
Pearson, W. A.
Peirce, Wm. H.
Penny, Edgar.
Phelps, F. A.
Phillips, Franklin.
Phillips, Geo. H.
Phipps, C. W.
Pitkin, S. H.
Platt, John.
Pollock, A. W.
Poole, Herman.
Poore, J. B.
Porter, Chas. T.
Porter, H. F. J.
Pratt, Chas. R.
Pusey, Chas. W.
Rand, A. C.
Rankin, T. L.
Raque, P. E.
Raynal, A. H.
Reed, Saml. G.
Reeves, Clifton.
Reist, H. G.
Richards, F.
Richards, F. H.
Rice, A. L.
Richmond, Geo.
Riesenberger, A.
Rites, F. M.
Robinson, A. W.
Robinson, J. M.
Rockwood, Geo. I.
Roelker, H. B.
Rogers, W. S.
Roney, W. R.
Ross, Ed. L.
Rowland, A. E.
Rowland, Chas. B.
Rowland, Geo.
Rowland, T. F.
Sanborn, F. N.
Sando, W. J.
Sangster, Wm.
Sanguinetti, P. A.
Scheffler, F. A.
Schmidt, C. R.
Schnuck, Edw. F.
Schoenborn, W. E.
Scholl, J.
Schroeder, A. M.
Schuhmann, Geo.
Schutte, L.
Scott, S. M.
Seaman, H. B.
Sedgwick, E. H.
See, Horace.
Sergeant, C. H.
Serrell, Jno. A.
Serrell, Wm. C.
Shankland, E. C.
Shaw, Geo.

Sheldon, T. P.
Shipley, Thos.
Sims, G. C.
Sinclair, Angus.
Smith, Éph.
Smith, J. M.
Smith, J. Waldo.
Smith, Oberlin.
Smith, S. H.
Smith, Sidney L.
Snell, H. I.
Snow, S. M.
Snow, Walter B.
Souther, Henry.
Sparrow, E. P.
Spaulding, H. C.
Spies, Albert.
Spilsbury, E. G.
Stangland, B. F.
Stetson, Geo. R.
Stevenson, A. A.
Stiefel, R. C.
Stiles, N. C.
Stillman, F. H.
Sterling, Allan.
Stratton, E. Platt.
Suplee, H. H.
Swasey, Ambrose.
Sweet, Jno. E.
Tabor, Harris.
Taylor, F. W.
Taylor, J. T.
Taylor, W. M.
Thayer, W.
Thomas, C. W.
Thomas, E. G.
Thompson, E. P.
Thomson, Jno.
Thorp, R. H.
Thurston, R. M.
Tibbals, G. A.
Tompkins, S. D.
Torrance, Henry.
Torrance, K.
Torrey, H. G.
Townsend, David.
Trautwein, A. P.
Treat, C. H.
Tremaine, E. G.
Trump, Chas. N.
Tucker, E. D.
Turner, Jno.
Turner, W. C.
Tyberg, Oluf.
Vanderbilt, Aaron.
Van Derhoef, G. N.
Varney, Wm. W.
Waldo, Leonard.
Waldron, F. A.
Walworth, A. C.
Ware, Justin A.
Warner, Worcester R.
Warren, B. H.
Washington, W. D.
Watson, Wm.
Weber, F. C.
Webber, S. S.
Webster, Hosea.
Webster, W. R.
Weeks, Geo. W.
Weil, Chas. L.
Wellman, Chas. H
Wellman, S. T.
Wells, J. L.
Whaley, W. B. S.
Wheeler, F. M.
Wheeler, Seth.
Wheelock, J.
White, M.
Whitehead, G. E.
Wiley, Wm. H.
Willcox, Chas. H.
Williams, F.
Williams, Thos. H.
Williston, A. L.
Wilson, J. E.
Wilson, J. F.
Wilson, W. R.
Winship, J. G.
Winther, C. A. G.
Woodbury, C. J. H.
Woolson, I. H.
Woolson, O. C.
Woolson, W. D.
Wood, A. J.
Wood, J. L.
Wood, M. P.
Wright, J. K.
Wurtz, E. V.
Wyman, H. W.
Yawger, Edwin.
York, H. W.
Young, W. S.
Zimmerman, W. F.

The first business of the session was the Annual Report of the Council and of the standing committees of the Society, which had been printed in advance and were read in abstract by the Secretary, as follows:

ANNUAL REPORT OF THE COUNCIL.

The Council would present to the Society, convened for its XXth Annual Meeting, the report of business which has been considered by it and of action which has been taken during the year.

The vacancy in the committee appointed by the Council,

pursuant to a resolution of the Society, to consider the question of standards for pipe unions, has been filled by appointing Mr. Axel S. Vogt. The committee, therefore, consists now of Messrs. W. J. Baldwin, George M. Bond, H. M. Herr, Stanley G. Flagg, and A. S. Vogt.

Under the provisions of Articles 9 and 16 of the Rules, Prof. William Cawthorne Unwin, of London, England, has been elected to honorary membership in the Society. Professor Unwin on being notified of his election presented to the Society Library copies of his publications on "The Testing of Materials of Construction" and on the "Development and Transmission of Power."

The Council has taken action with respect to the increasing number of duplicates which had accumulated in the Library, as the result of purchases, bequests, and other testamentary provisions. It seemed advisable to the Council to accede to the request which was made by the authorities of the University of Virginia, at Charlottesville, which requested the coöperation of scientific bodies in the replacement of the library of that institution, which had been destroyed by fire. After culling through the list of duplicates and using them with advantage for purposes of exchange, the remainder, including 311 bound volumes of journals, 25 sets of unbound journals, and 155 books, were presented to the University as a gift, for which due recognition and thanks were received.

Miss L. D. Allen, daughter of the late Horatio Allen, has made a gift of books from the library of her father, which possess a certain historic interest.

It was the purpose of the late W. F. Durfee, member of this Society, to present to this body his accumulated library, over which he had spent many years of effort and had gathered a considerable amount of unusual material. Some of the antiquities have become quite rare. The failing health of Mr. Durfee in the summer of 1899, which culminated in his death, made it impossible for him to see his way clear to the legacy which he had planned in his more fortunate days, and he approached the Society, before the final breaking down of his physical condition, with the request that the library should be purchased. The Council, on consideration of the value of the library and the conditions surrounding its transfer, at that time made an appropriation for the purchase of the library and its cases, and the

procedure of the transfer from Mr. Durfee's home to the Society house was in progress at the time that his death was announced. The library has been kept together so far as possible, and will be known as the "Durfee Collection."

The Council has been this year the recipient of certain gifts having a notable intrinsic value by reason of association. Mr. John Fritz, past President of the Society, has permitted the Society to acquire the most satisfactory oil painting of himself, which he had desired to retain concealed, with the purpose of having it come to the Society at a later date. This portrait by definite action is suspended behind the chair of the presiding officer (against Mr. Fritz's expressed preferences), and due acknowledgment has been made.

From Miss Cornelia J. Carll a most interesting gift has been received of a brush drawing in water color and sepia, which bears in the corner an autographic signature of Robert Fulton, and the date 1797. It presents a sketch of an aqueduct carrying a canal across a stream upon a lower grade, the plan being to use the fall of the water from the high-level canal as a means of towing the canal boats across the chasm. This picture has been framed with proper legend and is hung in the auditorium. It appears to belong to the time at which Mr. Fulton was interesting himself in the subject of canal engineering, and his treatise on this subject contains many cognate suggestions for propulsion, although it does not give specific reference to the design of this bridge. Proper vote of thanks has been sent to Miss Carll.

Mr. Alex E. Brown, member of the Society and engineer for the Smith Premier Typewriter Company, has been the means of securing for the Society the gift of a new and improved typewriter, to take the place of the former machine which had been worn out in the Society's service.

It will be recalled that at the annual meeting of 1898 a resolution was introduced to provide for the consideration by a committee of a project to hold certain meetings at the Society house in New York, between the periods of the regular semi-annual conventions, such meetings to be under the control of an executive committee of junior members, and designed, if this should be practicable, to enlist the interest and dignify the importance of the junior membership of the Society. Meetings under this provision were held in March and April and in October and

November. The topics for consideration have been "The Equipment and Function of the Floating Machine Shop 'Vulcan'"; "The Liquefaction of Gases," with special reference to Liquefied Air; "The Gas Engine" and "The Compound Locomotive." These meetings have been well attended by the senior members of the Society who could reach them, as well as by the juniors for whom they were in a sense primarily intended, and a report from the Secretary of the Executive Committee will be a feature of the proceedings of the annual meeting.

The subject has been brought up in the Council and considered whether it was advisable to arrange by a concession that the meetings of this Society should be held in the same week which is chosen by any other society. It was the result of a consideration of this subject that it was not desirable to pursue the proposition further, but that the dates and the methods of choosing them which now prevail, were as satisfactory as any that could be found.

At the Washington Convention a resolution was introduced in a paper by Mr. J. B. Stanwood, which passed the Council in the following form:

"*Resolved*, That the Council be requested to communicate with the American Institute of Electrical Engineers, to ascertain if that Institute will agree to appoint a committee to coöperate with a similar committee, to be appointed by the American Society of Mechanical Engineers, to determine and report upon a Standard Series of Capacities, Speeds, and Necessary Dimensions for Electrical Generators, for Direct-connection to Steam-engines. And, furthermore, if a favorable response be received, the President be requested, with the concurrence of the Council, to appoint a committee of five to coöperate with the committee to be appointed by the American Institute of Electrical Engineers for the purpose herein set forth."

It was the sense of the Council that time would be saved if the committee appointed to consider the subject should also be appointed a committee to confer; whereupon the Council approved the appointment of such a committee, to consist of Messrs. Stanwood, McFarland, Rohrer, Forbes, and Ball. It is expected that a report of progress from this committee will be a feature of the business of the annual meeting.

A letter has been received from Mr. Albert A. Hopkins, of New York City, suggesting to the Council the advisability of an action by the Society looking towards a suitable monument or memorial to be erected in Trinity churchyard in this city, where the remains of Mr. Robert Fulton are placed. The Council

appointed a committee, to consist of Messrs. Henning, Hunt, and Suplee, who have given extended consideration to the subject. They have secured the concurrence of the authorities of the Trinity Corporation and that of the available descendants of Mr. Fulton, and a movement is on foot to raise the necessary funds by subscription, within the limits of the Society itself, to place a suitable granite memorial, in the name of the Society, over the resting place of Mr. Fulton. The Committee will report in detail in its own name.

Mr. Alfred H. Raynal, representing the Committee of the resident members of the Society in Washington, has reported to the Council the consummation of an idea which was suggested too late for the Society to act upon it at Mount Vernon in May, on the occasion of the Society's visit to the tomb of Washington. It was that the Society should plant a memorial tree at a short distance from the tomb of Washington and present this tree to the custody of the Regents of the Mount Vernon Homestead. In the name of the Society Mr. Raynal presided at the planting of a white-oak tree, about 100 feet from the tomb, on May 13th. It is tree No. 6 in the series of such memorial trees, a thrifty white-oak. The Regents accepted the trust with proper expressions of recognition for the thought.

The Finance Committee has called the attention of the Council to the question of taking up the first mortgage now held by the former owners of the Society house. Their suggestion is that redeemable bonds should be issued in the membership, covering the amount of this first mortgage and bearing interest, and that as the Society might accumulate a surplus each year it should be expended for the redemption of these bonds. It is expected that this subject will be laid before the membership at large during the approaching winter.

It has been found inconvenient to permit the use of the Society's official letter-head by persons visiting the Society Library, who might claim the privilege of the use of the stationery which they found there and which was intended solely for the use of members. The Secretary has therefore been instructed to provide a different letter-head for use in the public parts of the Society house, from that which is used by officers of the Society on official business, and the Council has also directed that the use of the regular letter-head of the Society is to be restricted to officers of the Society upon official busi-

ness. This regulation will go into effect at once, and it is desired that the members of the Society will understand the necessity for the restriction and conform themselves to it.

The Council has received the following letter from the Institution of Civil Engineers of Great Britain:

"To the President and Council of the American Society of Mechanical Engineers.

"Gentlemen: In view of the intended International Exposition in Paris in the year 1900, it has appeared to the Council of this Institution not unlikely that some of the members of your Society may visit Europe in a more or less organized party in that year.

"We are desired by the Council of this Institution to say, that should such a step be taken, and should your members be able to visit England, the Institution of Civil Engineers would wish to welcome its professional brethren of the United States with a warm greeting, to receive them at the house of the Institution, and in such other ways as may be found agreeable, to take advantage of such a favorable opportunity of testifying their regard for the members of your Society.

"We have the honor to be,

"Gentlemen, yours very truly,

"J. Wolfe Barry, *President.*

"J. H. T. Tudsbery, *Secretary.*"

Pursuant to this inquiry, a circular letter was despatched in midsummer of this year, explaining the circumstances and enclosing a postal whereby the members might group themselves into the following classes:

1*st.*—Members who hoped to go to Europe in 1900 if an excursion by the Society was arranged.

2*d.*—Members unable to say whether they would go at the date of this inquiry, but would be able to decide only as the date drew nearer.

3*d.*—Members unable to go under any probable circumstances.

The fourth inquiry related to the preferred season of the year 1900 for such an excursion, if it should be organized.

The replies to these inquiries grouped the members into the following classes:

1*st.*

Members.	Ladies.	Members of Immediate Family.	Total.
257	165	89	511

No Preference.	May.	June.	July.	May or July.	Earlier.
13	107	14	96	20	7

2*d*.

Members.	Ladies.	Members of Immediate Family.			Total.
337	163		56		556
No Preference.	**May.**	**May or June.**	**June.**	**July.**	**May or July.**
83	102	2	6	96	48

A committee has been appointed to take up the question of securing satisfactory means of transportation for a possible party of this size and to fix upon the date which may be imposed by the conditions of transportation.

The Council would report for record in its *Transactions* the following list of deaths since the publication of its annual report in December, 1898: W. L. Chase, November 27; James Francis, December 1; Samuel McElroy, December 10; Hillary Messimer, December 10; J. C. Debes, December 13, 1898; M. C. Bullock, January 12; John R. Wagner, January 21; Geo. A. Barnard, February 8; John Kruesi, February 22; Fred'k Cook, February 25; Hiram Kimball, March 9; Hamilton A. Hill, March 18; A. E. Hunt, April 26; R. W. Bellhouse, April 3; Lewis Miller, February 17; Maurice A. Muller, May 21; Chas. A. Bauer, June 12; Chas. Whittier, August 28; Horace S. Smith, October 17; Edward L. Dent, October 19; W. F. Durfee, November 12, 1899.

The Council would report the following summary of the membership of the Society at the annual meeting of the Society, December, 1899. The list contains the names of those who have been elected preceding this meeting and excludes those who by persistent failure to pay the dues of the Society have allowed their membership to lapse.

Honorary Members	15
Members	1,417
Associates	123
Juniors	402
Total	1,957

The Council would also present the Report of its Tellers, appointed to count the ballots cast for members seeking to connect themselves with the Society just previous to the annual meeting. The report is as follows:

REPORT OF TELLERS OF ELECTION.

The undersigned were appointed a Committee of the Council to act as tellers, under Article 14 of the Rules, to scrutinize and count the ballots cast for and against the candidates proposed

for membership in their several grades in the American Society of Mechanical Engineers, and seeking election before the XLth meeting, New York, 1899.

They have met upon the designated day, in the office of the Society, and have proceeded to the discharge of their duty. They would certify, for formal insertion in the records of the Society, to the election of the following persons, whose names appear on the appended list, in their several grades.

There were 460 votes cast on the pink ballot, of which 15 were thrown out because of informalities. The tellers have considered a ballot as informal which was not indorsed with an autographic signature, or where the indorsement was made by a facsimile or other stamp.

H. H. SUPLEE,
GEORGE RICHMOND,
GUSTAVUS C. HENNING,
CHAS. H. LORING,
} *Tellers of Election.*

AS MEMBERS.

Adams, Henry.
Arnold, G. L. H.
Ball, Philip De C.
Bates, Edw. C.
Bowen, David R.
Bowman, Austin L.
Cash, Arthur W.
Charter, Jas. A.
Childs, Eugene.
Clark, Chas. B.
Clough, Wm. R.
Draper, Wm. L.
Durley, Richard J.
Farwell, Elmer S.
Fordyce, Jno. R.
Forsaith, Thos.
Fulton, Geo. R.
Gallagher, Thos. M.
Garbett, Joseph.
George, Jerome R.
Grafstrom, Edw.
Heikel, Daniel A.
Hill, Jno. W.
Honiss, Wm. H.
Hoxie, Wm. D.
Hutchinson, Arthur H.
Jenkins, M. L.
Kupferle, Edw.
Longstreth, Chas.
Lorenz, Wm. A.
Lovell, Alfred.
Lyman, James.
Makedansky, Alex. P.
Murphy, Jno. Z.
Noyes, Henry.
Oswald, William.
Parsons, Washington E.
Reed, Edgar.
Schwab, Chas. M.
Slack, Jno. R.
Spackman, Henry S.
Symons, Wilson E.
Warner, Robt. Lyon.
Westmark, Hans Olof.

AS ASSOCIATES.

Galbraith, Geo. W.
Greene, Harris R.
Jaquays, Homer M.
Luders, Peter W.
Marshall, Alfred.
Miller, Jas. W.
O'Brien, John.

PROMOTION TO FULL MEMBERSHIP.

Bacon, George Wood.
Carpenter, Henry Albert.
Colvin, Fred. H.
Hale, Robt. Sever.
Johnston, Wm. Atkinson.
Kearney, Alex.
Morehouse, Wm. Stephen.
Thomson, Francis Du Pont.

PROMOTION TO ASSOCIATE MEMBERSHIP.

Alexander, Harry.
Burgan, Abraham L.
Logan, Jno. Wood.

AS JUNIORS.

Alexander, Chas. A.
Bacon, Jno. L.
Baldwin, A. T.
Barnes, Stuart G.
Belsley, Clay.
Burditt, W. F.
Chadwick, Lee S.
Close, Ralph T.
Craig, Howard B.
Damron, C. W.
DeWolf, Edw. Chas.
Doughty, Wm. F.
Fairbanks, A. S.
Fitch, Jno. W.
French, Lester G.
Haight, Harry V.
Haskell, Geo. Owens.
Hatch, Tracy B.
Holeman, Louis A.
Holmes, Geo. Lewis.
Howe, Chas. M.
Hulett, John.
Hunter, Jas. Francis.
Lewis, Joseph E.
McKennan, Jacob B.
Miller, Elmer E.
Mortensen, Casper.
Murray, H. H.
Neureuther, A. H.
Ninde, Wm. E.
Nordmeyer, Louis Chas.
Price, A. M.
Pudan, Herbert W.
Reeves, Clifton.
Scudder, H., Jr.
Sedgwick, Earl H.
Smith, Abel I., Jr.
Smith, Orin G.
Standley, Albert H.
Swann, Jno. J.
Wilcox, P. S.
Wilkins, I. C. G.
Wilson, Wm. R.

At the close of the Report of the Council, the second order of business was the Report of the Finance Committee, which was as follows :

ANNUAL REPORT OF THE FINANCE COMMITTEE OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, 1898–1899.

For the fiscal year 1898–99 the Finance Committee of the American Society of Mechanical Engineers would respectfully report to the Council and the Society the following statements of receipts and expenditures which have passed under their direction on behalf of the Society during the year beginning November 15, 1898, and ending November 15, 1899.

Secretary's Balance Sheet for the fiscal year ending November 15, 1899:

Dr.		Cr.	
To receipts for the year	$34,542 07	By Cash to Treasurer	$34,542 07

Itemized statement of receipts and expenditures of the Society for fiscal year 1898–1899:

Receipts. Dr.		*Disbursements.* Cr.	
Initiation Fees	$2,430 00	Reprints and Publications	$5,739 52
Current Dues	23,459 39	Postage and Express	2,597 61
Past Dues	1,395 00	Salaries	7,749 00
Advance Dues	330 87	Office Expenses	400 38
Sales of Publications	1,512 17	Engraving	1,746 40
Binding	4 75	Contingencies (profit and loss)	24 00
Engraving	127 65	Binding *Transactions*	1,694 10
Life Membership (cash)	371 50	Meetings	1,556 07
Interest on Investment	1,252 50	Work of Committees	255 60
Office Expenses	6 40	Badges and Certificates	656 36
Mail and Express	32	Travelling	150 00
Badges and Certificates	559 75	Insurance and Safety Deposit	144 20
Hall Rentals	925 00	Rent, Interest, and Taxes	3,394 03
Room "	2,131 52	Printing — Circulars, Catalogues, Office Forms, etc.	3,128 40
Library	3 50	Stationery Supplies	323 13
Travelling	29 05	House Supplies and Furniture	592 27
Lighting	2 50	Library (book purchase and binding)	81 16
Check Collection Charges	20	Janitorial Supplies	150 15
		Fuel	177 45
		Lighting (gas and electric light)	380 30
		Laundry	341 20
		Repairs to House, Furniture, etc	1,138 02
		Interest on Investment	13 01
		Collection out-of-town checks	7 44
		Total regular Disbursements	$32,439 80
		Investment, M. E. L. A. bonds bought	2,700 00
Total Receipts	$34,542 07	Total Disbursements	$35,139 80
Cash in Treasurer's hands first of year	698 65	Cash on hand to balance	100 92
Total	$35,240 72	Total	$35,240 72
Cash in Treasurer's hands, forward	100 92		

At the time of this report there remains outstanding uncol-

lected accounts due the Society at the end of the year 1898-99, as follows:

From Members, Dues, etc.

50 men owe for the year just closed, 1898-9 at $15		$750 00
8 " " " " " " " " " $10		80 00
5 " " " " " " " " " and small balances		30 20
36 " " " dues from 1-3⅓ years		1,282 18
1 man owes for balance on volumes		46 85
Total, 100 men (5 per cent. of entire membership)		$2,189 18

From Miscellaneous Accounts.

1 society owes for hall rent	$50 00	
14 persons owe for room rent	160 50	
1 firm owes for electros	2 80	
3 persons owe for volumes and papers	147 45	
Total from 19 persons		360 75
Total amount outstanding and uncollected		$2,549 93

Due to action which has been taken this year by the Council, under Art. 19 of the Rules, on such men as owed a number of years' back dues and from whom we seemed to be able to get no satisfactory and definite responses to statements and letters sent them, the sum as shown above as due the Society at the end of the year 1898-99, *i.e.* $2,549.93, is practically all collectable and will without doubt be collected during the new year.

ASSETS AND LIABILITIES.

At the end of the year 1898-99.

Exclusive of such property as pamphlet copies of the papers, office furniture, etc., which is also owned by the Society.

Assets.

Bonds of the M. E. L. A. held by the Council as Trustees	$26,500 00
Stock of bound and paper copies of the Society's *Transactions*, Vols. I.—XIX. inclusive, on hand, estimating bound volumes at $6.00 each and paper bound at $5.00 each, the lowest prices at which they are ever sold	23,856 00
Outstanding indebtedness due the Society as itemized above	2,549 93
Cash on hand and in bank, as reported above	100 92
Total assets	$53,006 85

The above statement of assets, moreover, does not cover the stereotype plates of the volumes of *Transactions*, nor the electro-

types of the cuts used in illustrating them. It covers only assets which are convertible under favorable conditions into cash. Nor does it include office furniture and fixtures in use.

The Society has as a liability at this date a running account with the firm who prints its *Transactions*, which will be paid at once out of the receipts of the new year 1899–1900.

MECHANICAL ENGINEERS' LIBRARY ASSOCIATION.

COPY OF THE ANNUAL REPORT OF THE TRUSTEES OF THE MECHANICAL ENGINEERS' LIBRARY ASSOCIATION, 1898–1899.

The summary of receipts and disbursements of the Trustees from November 15, 1898, to November 15, 1899, is appended.

Secretary's Balance Sheet, year 1898–1899:

Dr.		Cr.	
To balance on hand first of year	$1,194 09	By expenditures as itemized below	$4,856 41
To receipts as itemized below.	3,913 00	" cash on hand	250 68
	$5,107 09		$5,107 09
To cash on hand	250 68		

Itemized Statement of Receipts and Expenditures of the Association for fiscal year 1898–1899:

Dr.		Cr.	
Receipts, Fellowship Fund	$150 00	Interest on mortgage	$1,402 50
" Sinking Fund	375 50	" " bonds	1,600 00
" office rent	3,375 00	Salaries	780 00
Interest on investment, 5 x $2.50 (9 bonds owned, but four bought after July, 1899, interest was payable)	12 50	Equipment (furniture), etc.	62 25
		Library and book purchase	107 66
		Stationery and printing	4 00
Total receipts for year	$3,913 00	Total expenditures	$3,956 41
Cash on hand first of year	1,194 09	Investment, 9 bonds bought	900 00
	$5,107 09		$4,856 41
Cash on hand first of year, 1899–1900	250 68	Cash on hand	250 68
			$5,107 09

All money due the Association at the end of this year (except $20, subscriptions from three men) has been paid, and all outstanding accounts against it are paid to date of this report.

ASSETS AND LIABILITIES.

Assets.

Cash on hand as above	$250 68	
House and lot, 12 W. Thirty-first Street, New York City	65,000 00	
Furniture and equipment	5,000 00	
Books and manuscripts	10,700 00	
Bonds	900 00	
Subscription due by 3 men	20 00	
Total assets		$81,870 68

Liabilities.

First mortgage held by N. Y. A. of M.	$33,000 00	
Second mortgage bonds held by members of A. S. M. E.	4,600 00	
Second mortgage bonds held by Council of A. S. M. E. as an investment	26,500 00	
Total liabilities		$64,100 00
Excess of assets over liabilities		$17,770 00

At the close of the reading of the reports the President called for the presentation of reports of progress from the professional committees of the Society. The Committee on Standard Methods of Conducting and Reporting Steam Engine Trials, reported progress through its chairman, Mr. Francis H. Boyer, as follows:

Mr. Francis H. Boyer.—Mr. President: In behalf of the Committee, I wish to report progress and ask for further time before we make the report. As part of our membership, as is well known, are European members of the Association, the time taken in correspondence has been necessarily considerable. I would state that we have our matter very nearly completed and agreed upon, and I think not later than the spring meeting, or later than the meeting next fall, we will be in condition to make a report to the Society.

The second committee called on was that to whom had been entrusted the consideration of preparing and erecting in Trinity churchyard a memorial on behalf of the Society to the memory of Robert Fulton. This was presented by the Chairman of the Committee, Mr. Gus C. Henning, as follows:

FULTON MEMORIAL.

Mr. Gus. C. Henning.—The Committee has taken the matter in hand of erecting a suitable memorial to Robert Fulton, and

has been met very cordially by the corporation of Trinity Church, the comptroller of which happens to be the husband of one of the four surviving granddaughters of Robert Fulton. They have done everything that is possible to encourage the project. They have informed us that an available space on the Rector Street side of Trinity churchyard, which is not occupied for tombs or vaults, would be put at our disposal, so that the monument would be plainly visible from all sides and directly approachable by a footpath leading south from the church; it would be placed along Rector Street, so that it could be seen from Rector Street as well as from the church, in a very convenient location. The comptroller himself said that he would personally do everything that he could to help the project along. As you know, we have now $1,068, collected from about one hundred members in less than ten days, and I think it will not be long before we shall have enough money to begin the work. The designs will, of course, soon be taken up. The idea is to remove the body from the Livingston vault in which it now lies, in a coffin properly marked with a name-plate—which has not been defaced in any way—lying near the southwest corner of Trinity Church, the third vault south, marked as the Livingston family vault. It is proposed that the coffin with the body be taken out and reinterred in or under this monument, so that the resting place will be solely that of Robert Fulton. The character of the monument has not yet been decided upon, because that depends upon the amount of money that will be available. But the idea is to make a permanent monument which is not likely to be destroyed by time or weather, and which will stand out boldly and characterize the noted person whom it is supposed to commemorate. I suppose in connection with the unveiling of the monument there will be some ceremonies, which will be under the management of our Society. The technical press has also suggested on its own behalf that all engineers in the country assist in the erection of this monument, and therefore we may expect assistance from engineers who are not members. All assistance is welcome; we do not care how much or how little it is. It looks now as though we should be able to consummate the project in a very short time, and I think before the next annual meeting the Committee will be able to report the completion of the work it has undertaken.

Mr. Wm. D. Forbes, on behalf of the Society's Committee on

Standards for Direct-Connected Generating Sets, presented the report of the Committee as follows:

Mr. Wm. D. Forbes.—Owing to the unavoidable absence of Mr. J. B. Stanwood, Chairman of the Committee on Standards for Direct-Connected Generating Sets appointed by you, he has requested that the Committee report progress and has asked me to say, further, that the answers to the circulars sent out to the various engine builders, in connection with this matter of standardization, show a strong desire to help the Committee in their work, so that ultimately a satisfactory standard can be arrived at.

The Committee draws your attention to the fact that there is a large amount of work yet to be done, before anything like a definite report can be made, but it feels very much encouraged by the hearty coöperation of the large number of engine builders who have answered the series of questions sent them, and the evident interest taken by the Committee appointed by the American Institute of Electrical Engineers, in the work. It is hoped that before the next meeting of our Society the suggestive plans for this standardization can be laid before the meeting for discussion.

The Committee appointed by the Council to arrange for a series of meetings to be conducted by Junior Members of the Society, presented its report through its chairman, Mr. B. C. Ball, as follows:

Mr. Bert C. Ball.—Pursuant to the plan outlined in the report of this Committee, which was presented at the Washington meeting, monthly meetings at the Society house have been held during the past autumn.

In October, Mr. Henry E. Longwell read a paper on the Westinghouse Gas Engine, and in November a paper by Mr. Fred H. Colvin was read, the subject being Compound Locomotives. Both of these meetings were well attended, the junior members constituting about twenty-five per cent. of the attendance.

After the reading of the paper, the subject was discussed informally. Arrangements have been practically completed for the papers to be presented at all of the meetings of the winter and spring, and it is expected that an interesting series of papers will be presented.

Some criticism has been made that these meetings are not conducted according to the plan of the original committee, and that they are becoming less and less Junior meetings.

In answer to these criticisms, we can only say that we have used every endeavor to promote the Juniors' participation in the meetings, and will continue to do so.

Of the four papers already presented, two have been by Juniors, and it is expected that about the same proportion will be maintained during the rest of the year.

The Committee will be very glad to receive from the members any suggestions which they may have to offer, regarding papers to be presented or the general conduct of the meetings.

The President then called for the presentation by the Committee appointed to consider a possible revision of the Standard Code for Conducting Steam Boiler Trials, which had been presented to the Society in 1885. It was explained that this report had been presented first at the New York meeting of 1897 two years ago, and again at the annual meeting of last year (1898), and at the spring meeting of 1899, and that many of the suggestions which had been made by the members of the Society in discussion at these meetings had been incorporated by the Committee, and that the report as approved by the Committee, together with the complete discussion, had been distributed to the membership in advance of this meeting, with a notice that it was the wish of the Committee that, if possible, their labors might be terminated by action at this time. Whereupon the Secretary read a draft of the resolutions which had been prepared with a view to consummating the work of the Committee. The resolutions were as follows, and were duly seconded:

Resolved, That the Society accept the report of its Committee on a Revision of the 1885 Code for Conducting Boiler Trials, with its thanks to the Committee for the faithful and continued labors upon the subject referred to them.

Resolved, That the report and its recommendations as to a revised code be printed in the *Transactions* and the use of the Standard Method of 1899 be recommended to the members of the Society.

Resolved, That upon the completion of the final detail of its work after this meeting, the Committee be discharged.

In the brief favorable debate on the resolutions, Col. E. D. Meier spoke as follows:

Mr. E. D. Meier.—Mr. President, I believe that we owe more to this Committee than the ordinary vote of thanks. Of course the vote of thanks is included in these resolutions in the usual manner. But I for one would like to express personally what I feel in regard to the labors of this Committee. I have read the

report and the discussions with a great deal of interest, and I know the difficulties which were in the way of the Committee. When the Committee of 1885 formulated the Standard Code for Conducting Boiler Trials they had in view practically one kind of coal, or at most two kinds. The only coals that were in question then were the anthracite coal of the Lehigh Valley and other coals of eastern Pennsylvania, and the Cumberland coal as bituminous coal. The necessity for revision of the Code arose largely from the fact that in the application of this Code to boiler trials in the middle West and in the far West a great many difficulties were encountered, and there was quite an opposition to certain rulings of the old Code, especially by members in the West, and I must say that I was not very far from the front rank in this opposition. We had felt many of the provisions to be unwise, and naturally we pressed our own side of the case as strongly as we knew how, and you will remember that there was quite a discussion at the Detroit meeting and at other meetings as well. I wish to say for the Committee that they have borne the brunt of the attack nobly. They have given due weight to everything that was urged which had a foundation in fact and in fairness, and they have succeeded in finally drawing up a report which is as fair and as good a structure as it is possible for any committee that might be appointed in any technical society in the world to produce, and I believe that that Code, as formulated in this report, will be used not only by the members to whom it is specially recommended, but it will become the standard for the United States and will be copied abroad as well. It is a great deal better than anything I know of in any foreign language.

The resolutions proposed were thereupon unanimously adopted.

Under the provision for the presentation of motions and resolutions, Mr. Gus. C. Henning, on behalf of a Committee of the Council appointed to consider this question, reported in detail as to the securing of special transportation facilities for the Society upon a trip under contemplation, pursuant to the invitation recorded elsewhere from the Institution of Civil Engineers of Great Britain.

The report presented by Mr. Henning was as follows:

Mr. Gus. C. Henning.—The preliminary circular sent out in midsummer, concerning the proposed trip to England and Paris,

brought back replies that something over five hundred persons hoped to be able to go.

The Committee was immediately directed to see what arrangements could be made with respect to transportation. For a party of this size two courses seem to be open. The first is to have each individual make arrangements for himself, either directly or through a tourists' agent; or, secondly, to try and arrange to get the party together at one or two dates, so as to fill one or two steamers completely with the party of friends. If the first policy seems most desirable, it is none too early to make the necessary arrangements. If the second plan is a practical one, it is imperative that the arrangement be closed at once, and to do this it will be required that the contract sum of twenty-five dollars for each person be paid to the steamship line within two or three weeks at the latest.

Messrs. Raymond & Whitcomb quote a price for the round trip of $256 from New York to Southampton, to London, Dover, Folkstone, and Paris, with a week each in London and Paris, and return via Cherbourg to New York on steamers of the "Barbarossa" type; they give the same accommodations on steamers of the "Kaiser Wilhelm der Grosse" class for $316. This latter alternative does not offer the use of a single steamer for an exclusive party, but gives the flexibility of choice to the individual member.

The Hamburg-American Line has quoted to the Committee the following propositions:

The exclusive use of steamers as follows—the fare quoted is New York to London, via Plymouth, one way only: S. S. "Fuerst Bismarck," sailing May 31st; 550 persons, at $110. S. S. "Pennsylvania," sailing June 2d; 340 persons, at $87.50. S. S. "Phœnicia," sailing May 26th; 200 persons, at $61.75 each. S. S. "Batavia," sailing June 5th; 255 persons, at $56.75 each —provided payment is received immediately from a sufficient number to warrant the Committee in making a contract for the steamer. Members will make their own arrangements with respect to the return journey, at such dates as suit them, and it should be observed that this differs from the Raymond & Whitcomb proposition in that it includes nothing with respect to the stay in either London or Paris, and imposes no limitations as to date of return. It is obvious, however, that the congested condition of the steamer lines makes it vitally important that

this matter should be carefully arranged before leaving this side.

Perhaps advantageous use may be made of Allan Line steamers sailing from Montreal, if the New York plan falls through.

In view of the fact that if a party is formed and an exclusive steamship is to be secured for the party, it is imperatively necessary that action be taken at once.

All members will appreciate that by reason of the volume of travel expected during the summer of 1900, the transportation companies are within their rights in asking us to decide very promptly.

Under motions and resolutions the following matter was also presented:

Mr. E. D. Meier.—Mr. President, there has come up in the Council the question of revising the Standards for Pipe Flanges, which had been proposed in 1894 by a committee of this Society. It appears that the manufacturers of pipe and fittings and of such flanges have found some difficulty in conforming to this standard —practical difficulties which perhaps were not duly weighed by our Committee—and have appointed a committee of their own, which has established standards differing slightly from ours. It therefore seems desirable that we should have a committee to go over the thing, possibly jointly with them. Whether and how they want to meet with the Committee from the Association of Manufacturers, might be safely left to the Committee. I beg therefore to move as follows:

Resolved, That a committee of five, consisting of Messrs. C. W. Nason, Edward F. Bates, John E. Sweet, A. J. Caldwell, and A. H. Jarecki, be appointed to consider and report upon what revision, if any, is desirable with respect to the Standards proposed in 1894 by the Committee of the Society in the matter of flanges for pipes.

The Secretary read on behalf of Messrs. Ball, Van Derhoef, and Lewis, appointed at the previous session, the report of the tellers appointed to count the ballot for officers. The report was as follows:

REPORT OF TELLERS.

The Committee of Tellers appointed last evening to count ballots cast by the members for officers of the American Society of Mechanical Engineers, for the year 1899-1900, begs to submit the following report:

Total ballots cast	522
Total informal ballots	10
Total ballots counted by tellers	512

Of the regular ballot counted by the tellers, they would report the following result:

For President.

Charles H. Morgan	511
Scattering	Not any

For Vice-Presidents.

Jesse M. Smith	508
Stevenson Taylor	518
David Townsend	508
Scattering	Not any

For Managers.

Francis H. Boyer	513
John A. Brashear	514
A. H. Raynal	509
Scattering	Not any

For Treasurer.

William H. Wiley	512
Scattering	Not any

Our count, therefore, shows the election of the regular nominees.

Respectfully submitted,

B. C. Ball,
Geo. N. Van Derhoef,
D. J. Lewis.

At the completion of this announcement the President appointed Messrs. John Fritz and E. D. Meier a committee to escort the President-elect, Mr. Charles H. Morgan, of Worcester, to the platform, where he was welcomed by the acting President with the handshake of greeting. Mr. Morgan accepted, in brief, fitting words, the duties and responsibilities which his associates had laid upon him.

The meeting then proceeded to the discussion of the professional papers allotted for the morning. The papers by Messrs. R. H. Thurston, J. A. Laird, H. T. Eddy, and George M. Peek, were entitled respectively, "The Steam Engine at the End of the Nineteenth Century," "The Berthier Method of Coal Calorimetry," "Test of Two Pumping Engines at St. Louis Water

Works," "A New Graphic Method of Constructing the Entropy-Temperature Diagram of a Gas or Oil Engine," and "Pressure in Pipe Due to Stoppage of Flowing Liquid." The discussion of these papers was participated in by Messrs. Charles T. Porter, J. B. Stanwood, J. H. Kinealy, and Wilfred Lewis.

On the afternoon of Wednesday the greater majority of members who had no other definite business assignments accepted an invitation which had been extended to join a party to visit the shops of Hewes & Phillips, at Newark, where the Diesel motor was running—not in any exhibition sense, but as erected for tests in the shop. Others availed themselves of the invitations which had been extended by various hosts.

THIRD SESSION. WEDNESDAY EVENING, DECEMBER 6TH.

This session had been allotted principally to the discussion of the paper by Prof. M. P. Higgins, on "Education of Machinists, Foremen, and Mechanical Engineers." Three papers were presented before this, however, as follows: A. L. Rice, "Liquefaction of Gases;" P. M. Chamberlain, "Curved Glass Blue Print Machine," and "A Metal Dynagraph," but, from the nature of their character, they received no discussion. The paper by Mr. Higgins had been carefully distributed in advance of the meeting, with special requests for discussion thereon, and in its presentation the following persons took part: Rear-Admiral George W. Melville, Messrs. F. R. Hutton, R. H. Thurston, Charles W. Pusey, Charles L. Griffin, Oberlin Smith, William Lodge, L. S. Randolph, William Barclay Parsons, George I. Alden, W. T. Magruder, Stephen W. Baldwin, H. Wade Hibbard, C. B. Richards, H. S. Haines, J. B. Johnson, Robert W. Hunt, W. S. Rogers, John Fritz, A. L. Williston, James Christie, Horace See, C. L. Weil, D. S. Jacobus, P. M. Chamberlain, O. C. Woolson, F. A. Halsey, and Angus Sinclair. The discussion was prolonged to a late hour, and it was a general opinion that it should be taken up anew at some later meeting, with the view to further presentation of discussion and points of view concerning it.

FOURTH SESSION. THURSDAY MORNING, DECEMBER 7TH.

The papers allotted to this meeting were as follows: By Mr. Herman Poole, entitled, "Experiments on Using Gasoline Gas

for Boiler Heating;" by Mr. C. H. Benjamin, "Friction of Steam Packings;" by Mr. F. C. Wagner, "Friction Tests of a Locomotive Slide Valve;" by Mr. A. J. Frith, "A Note on Fly-Wheel Design;" by Mr. James McBride, "A Broken Fly-Wheel and How It Was Repaired;" by Mr. C. H. Robertson, "An Efficiency Test of a One Hundred and Twenty-five Horse-Power Gas Engine;" by Mr. J. F. W. Harris, "Strength of Steel Balls;" by Messrs. M. White and F. W. Taylor, "Colors of Heated Steel Corresponding to Different Degrees of Temperatures." The discussion was participated in by Messrs. Charles Longstreth, Fred H. Colvin, F. A. Halsey, G. Lanza, R. A. Smart, George Schuhmann, George M. Basford, Charles T. Porter, W. T. Magruder, G. C. Henning, William Kent, William Sangster, John E. Sweet, Francis H. Boyer, James McBride, James Christie, H. H. Suplee, A. H. Raynal, R. H. Thurston, Edwin Rudd, Oberlin Smith, William F. Mattes, Henry Souther, Henry L. Gantt, John Pratt, Charles W. Thomas, H. M. Howe, George R. Stetson, A. L. Williston, John A. Brashear, W. F. Burleigh, M. P. Higgins, F. J. Miller, William Metcalf, and C. E. Sargent.

The popular excursion of the afternoon was to the power plant of the Waldorf-Astoria Hotel and to the elevator plant of the Lorraine Hotel.

In the evening the regular annual reception, which has formed so important a feature of the New York meetings, was held at Sherry's, Forty-fourth Street and Fifth Avenue. The President of the Society and the President-elect received the members, beginning at nine o'clock, and, after the officers' reception, dancing was enjoyed in the handsome ballroom. Supper was served over a considerable interval, to prevent the uncomfortable crowding. Nearly seven hundred persons were present.

Closing Session. Friday, December 8th.

The papers of this session were as follows: Mr. W. J. Keep, "Impact;" Mr. Walter C. Kerr, "The Southern Terminal at Boston;" Mr. F. H. Stillman, "High Hydrostatic Pressures and Their Application to Compressing Liquids. A New Form of Pressure Gauge;" Mr. G. I. Rockwood, "The Value of a Horse-Power." The debate upon these papers was participated in by Messrs. W. T. Magruder, J. H. Kinealy, G. I.

Rockwood, William Kent, R. H. Thurston, John Platt, R. P. Bolton, A. F. Nagle, G. C. Henning, D. S. Jacobus, William Da H. Washington, R. H. Thurston, and A. H. Raynal.

In connection with the last paper, by Mr. George I. Rockwood, he offered a motion that a committee of the Society should be appointed by the Council, to receive and consider the opinions of engineers who might care to express themselves on the question of the taking of testimony in the condemnation proceedings with respect to water powers which were required by the city and other users, and how that power should be valued in adjusting equitable damages. His motion was that it be referred to the Council, with power to appoint a committee to consider the proper way to investigate the proper value of a water power.

After some discussion as to whether it was the intention of the mover and seconder of this resolution (Mr. Raynal) that this reference should be mandatory upon the Council or simply a suggestion to that body, the motion as presented by Mr. Rockwood was passed.

The President then called upon Mr. Carleton W. Nason, Chairman of the Committee on Standardization of Pipe Flanges, to present the report of the Committee, which was as follows:

REPORT OF COMMITTEE ON FLANGE STANDARDIZATION, APPOINTED AT NEW YORK MEETING, DECEMBER 6, 1899.

Owing to the absence of two of the Committee just appointed, at this meeting, a full analysis of the subject is impossible, but as there have been some changes made in the standard suggested by the Flange Standardization Committee of the New York meeting in December, 1892, it seems advisable that a brief *résumé* of the subject should be given, covering the time that has elapsed during the interim to date.

The table as suggested is first heard of as having been considered at a meeting of the Master Steam and Hot Water Fitters' Association of the United States, held at Chicago, in June, 1893. At this meeting a committee on the subject, which had been appointed by that society, made a report, in which the table suggested by the A. S. M. E. Committee, after full discussion on the subject, was adopted as a whole, and its use recommended to and by all members of the Association.

It appeared, however, not long after, that the table as a whole did not meet the entire approval of manufacturers of products which involve the use of flanges, nor of some of the members of the Association, not present at their Chicago Convention, and on request of members of the several committees, a joint session of the Master Steam Fitters' Association, Committee of Manufacturers, and the A. S. M. E. Committee was held at our New York rooms on July 18, 1894.

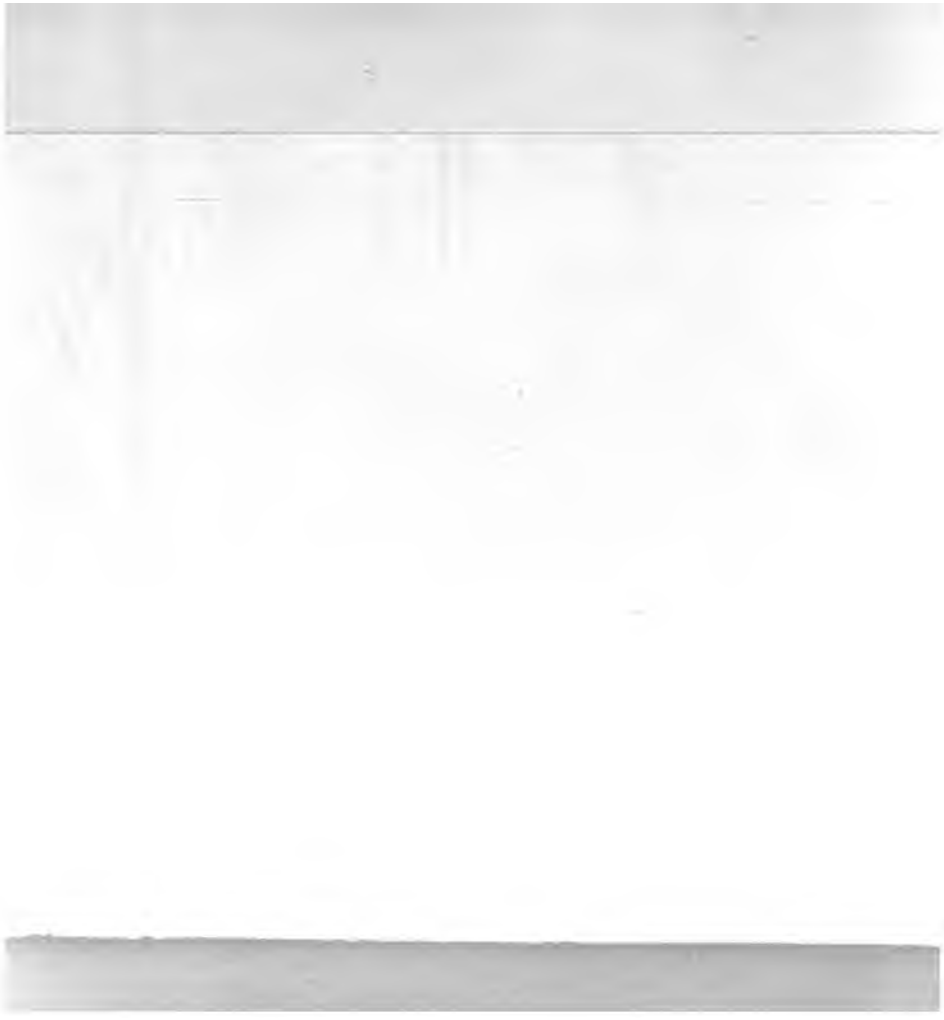
This meeting was well attended, and considerable time was devoted to details of the subject; and although the original scale, as a whole, was approved both by the Master Steam Fitters' Committee and that of the manufacturers, it was deemed by them advisable to make certain changes in the flange diameters of several of the sizes, from 12 inches down. These changes were made in the 2½-inch, 3½-inch, 4-inch, 6-inch, 9-inch, and 12-inch sizes, the outside diameters as finally agreed upon being as follows:

	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
Internal diameter of pipe	2	2½	3	3½	4	
Diameter of flange	6	7	7½	8½	9	
Internal diameter of pipe	4½	5	6	7	8	9
Diameter of flange	9½	10	11	12½	13½	15
Internal diameter of pipe	10	12				
Diameter of flange	16	19				

In all other particulars it was understood that the suggested scale was satisfactory. We quote as follows from the Joint Committee's report:

"It being understood by the majority of those present that the dimensions proposed in the Committee's standard, with the exception of diameters, was generally satisfactory, and that as no objection was raised or discussion held regarding larger sizes of pipe diameters than 12 inches, the following would be the scale, as a whole, which was recommended for the adoption of all manufacturers and others interested."

Nevertheless, it appeared that the subject had not reached a finality, for a very few days after this meeting was held, notices were received from secretaries of the two other committees that there had been a wish expressed on the part of the manufacturers, that an increase in bolt circle diameters which would be more in harmony with the larger flange diameters should be agreed upon, and a meeting of the Joint Committee was therefore held at the office of the Master Steam Fitters' Association,



early in August, 1894. At this meeting the standard of July 18, 1894, was reaffirmed, with the exception of the following changes in larger bolt circle diameters:

2½-inch became	5¼-inch instead of	5½-inch.
3½-inch became	7-inch instead of	6½-inch.
4-inch became	7½-inch instead of	7½-inch.
6-inch became	9½-inch instead of	9⅝-inch.
9-inch became	13½-inch instead of	13-inch.
12-inch became	17-inch instead of	16½-inch.

A typographical error in the thickness of 26-inch and 28-inch pipe for light pressure was, at the same time, corrected; 26-inch becoming 1⅜-inch instead of 1⅞-inch, and 28-inch becoming 1 7/16-inch instead of 1 5/16-inch.

Among several reasons urged at this meeting for increase of the bolt circle diameters, was one which, from a manufacturer's point of view, seemed advisable; namely, that in connecting a flanged angle valve to a pipe flange, there were instances in which the necks of the valves were so short that it was impossible, with the former lesser bolt circle diameter, to insert the bolts and nuts around the valve neck, which would appear perhaps to be a justifiable reason for an increase, which otherwise would be regarded as unnecessarily increasing the diameters and weights of the several sizes.

Immediately after the above date, Mr. Edward P. Bates, of Syracuse, who is now a member of this Society's Committee, undertook the dissemination of the finally adopted standard and prepared a number of carefully made charts, giving the entire table of the actual diameters of all sizes of flanges up to 48-inch pipe size, and they have been, we learn, very widely distributed throughout the country. This is reproduced on a one-fourth scale in the folder (Fig. 19).

In this table, however, an error crept in through the dating of the chart as of July 18, 1894, instead of the following August, at which time the changes were made and finally adopted.

This error has naturally given rise to some correspondence, owing to the fact that in the first edition of Kent's engineers' pocketbook, in the table of pipe flange standards therein published, he gave the bolt circle diameters as adopted July 18th, instead of those adopted at the August meeting. This we learn has been corrected in a later edition, and there is therefore not likely to be further misunderstanding on the subject.

Although the dimensions of several of the sizes may appear on first examination to be unnecessarily large, it may be said in favor of the adoption of the final August (1894) scale that already a large number of cards have been issued and adopted by a notable number of the manufacturers of cast-iron fittings, flanges, and valves. Also the ample space left between the inside surface of the bolts and the interior of the pipe, leaves room for the adoption, at the will of the user, of any one of the several forms of gasket that may be preferred. Thus, it may be either wide or narrow; it may be caged with a lip and groove at the edge of the pipe opening, or it may be held with tongue and groove at any point in the flange face between the interior hole and the inside bolt surface.

From the above it will appear that the last standard has already been largely adopted and propagated, which suggests the question whether a standard which, although somewhat irregular and possibly large in some of its dimensions, and which has become generally known and adopted, is not, on the whole, better than a newer one, the creation of which would again open up the entire subject, and involve even more uncertainty on the question than that which formerly existed.

This we beg to refer to the Society for discussion.

A copy of the table as finally issued is herewith appended.

Respectfully submitted,

CHAIRMAN FLANGE STANDARDIZATION COMMITTEE.

After pleasant words of salutation by the President, and expressing his thanks for the coöperation which the members had shown to him in the work of his office, he pronounced the meeting adjourned.

The city of Cincinnati, Ohio, has been fixed upon as the place for the spring meeting, the date to be a matter of adjustment, as may be later decided upon.

SCHEDULE OF STANDARD FLANGES.

Adopted August, 1894, by a Committee of the Master Steam and Hot Water Fitters' Association, a Committee of the Society of Mechanical Engineers of the United States, and the leading Valve and Fitting Manufacturers of the United States.*

Pipe size, inches.	Pipe thickness, $\frac{P+100}{.4S}$ $d+.333\left(1-\frac{d}{100}\right)$ S-18,000 lbs.	Thickness, nearest fraction, inches.	Stress on pipe per square inch at 200 lbs.	Radius of fillet, inches.	Flange diameter, inches.	Flange thickness at hub for iron pipe, inches.	Flange thickness at edge, inches.	Width flange face, inches.	Bolt circle diameter, inches.	Number of bolts.	Bolt size diameters, inches.	Bolt length, inches.	Stress on each bolt, per square inch at bottom of thread at 200 lbs.
2	.409	7/16	460	1/4	6	1	7/16	2	4 3/4	4	5/8	2	825
2 1/2	.429	7/16	550	1/4	7	1 1/4	7/16	2 1/4	5 1/2	4	5/8	2 1/4	1,050
3	.448	7/16	690	1/4	7 1/2	1 1/4	7/16	2 1/4	6	4	5/8	2 1/2	1,330
3 1/2	.466	1/2	700	1/4	8 1/2	1 1/4	7/16	2 1/2	7	4	5/8	2 3/4	2,530
4	.486	1/2	800	1/4	9	1 1/4	7/16	2 1/2	7 1/2	4	5/8	2 3/4	2,100
4 1/2	.498	1/2	900	1/4	9 1/4	1 1/4	7/16	2 1/2	7 1/2	8	5/8	3	1,430
5	.525	1/2	1,000	1/4	10	1 1/4	7/16	2 1/2	8 1/2	8	5/8	3	1,630
6	.563	9/16	1,060	1/4	11	1 1/4	7/16	2 1/2	9 1/2	8	5/8	3	2,360
7	.60	9/16	1,120	1/4	12 1/2	1 1/4	7/16	2 3/4	10 3/4	8	5/8	3 1/4	3,200
8	.639	9/16	1,280	1/4	13 1/2	1 1/4	7/16	2 3/4	11 3/4	8	5/8	3 1/4	4,190
9	.678	5/8	1,310	1/4	15	1 1/4	7/16	3	13 1/4	12	5/8	3 1/2	3,610
10	.713	5/8	1,330	1/4	16	2	7/16	3	14 1/4	12	5/8	3 1/2	2,970
12	.79	5/8	1,470	1/4	19	2	7/16	3 1/2	17	12	5/8	3 1/2	4,280
14	.864	5/8	1,600	1/4	21	2	7/16	3 1/2	18 3/4	12	5/8	4 1/4	4,280
15	.904	5/8	1,600	1/4	22 1/4	2	7/16	3 1/2	20	16	5/8	4 1/4	3,660
16	.946	1	1,600	1/4	23 1/2	2 1/4	7/16	3 3/4	21 1/4	16	5/8	4 1/4	4,210
18	1.02	1 1/16	1,690	1/4	25	....	7/16	3 1/2	22 3/4	16	1	4 3/4	4,540
20	1.09	1 1/16	1,780	1/4	27 1/2	....	7/16	3 3/4	25	20	1	5	4,490
22	1.18	1 3/16	1,850	1/4	29 1/2	....	7/16	3 3/4	27 1/4	20	1	5 1/4	4,320
24	1.25	1 1/4	1,920	1/4	32	....	1/2	4	29 1/4	20	1	5 1/4	5,130
26	1.30	1 5/16	1,980	1/4	34 1/4	....	1/2	4 1/2	31 1/4	24	1	5 1/4	5,030
28	1.38	1 3/8	2,040	1/4	36 1/2	....	1/2	4 1/2	33 1/4	28	1	6	5,000
30	1.48	1 1/2	2,000	1/4	38 3/4	....	1/2	4 1/2	35 1/4	28	1 1/8	6 1/4	4,590
36	1.71	1 3/4	1,920	1/4	45 3/4	....	1/2	4 1/2	42	32	1 1/8	6 1/4	5,790
42	1.87	2	2,100	1/4	52 3/4	....	1/2	4 1/2	48 1/4	36	1 1/4	7 1/4	5,700
48	2.17	2 1/4	2,130	1/4	59 1/2	....	1/2	4 3/4	54 3/4	44	1 1/8	7 3/4	6,090

* *Committee, American Society of Mechanical Engineers.*—Carleton W. Nason, *Chairman;* Andrew J. Caldwell, Alexander H. Jarecki, Frank H. Ball. *Committee, Master Steam and Hot Water Fitters' Association of the United States.*—Edward P. Bates, *Chairman;* A. C. Walworth, Chas. J. Gillis.

No. 827.*

REPORT OF THE COMMITTEE ON THE REVISION OF THE SOCIETY CODE OF 1885, RELATIVE TO A STANDARD METHOD OF CONDUCTING STEAM-BOILER TRIALS.

To the American Society of Mechanical Engineers.

Gentlemen: The undersigned Committee, to which was submitted the revision of the Society Code of 1885, relative to a standard method of conducting steam-boiler trials, reports as follows:

The Committee of 1885 presented a full statement of the principles which governed it in the preparation of the Code of Rules at that time recommended. These principles covered the ground in an admirable manner, so far as the practice of boiler testing had been perfected, and we are in unanimous accord with the sentiments which the report of that Committee expressed. During the interval of thirteen years which has passed, methods and instruments have in some measure changed. Improvements have been made in the instruments for determining the moisture in steam. The throttling and separating forms of calorimeters have displaced the barrel and other types of steam calorimeters referred to in the previous report. Attention has been devoted to the determination of the calorific value of coal, and a number of coal calorimeters have been brought out and successfully used for this purpose. It has come to be a practice with many experts to include in the table of results of boiler tests the percentage of "efficiency," or proportion of the calorific value of the coal which is utilized by the boiler. Specifications and contracts are in some cases drawn up, provid-

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

ing for certain percentages of efficiency instead of a specified evaporation. The analysis of flue gases is receiving more attention than formerly, not only in our educational institutions, but also in the regular practice of engineers who make a specialty of boiler testing.

Your Committee submits a revised Code, termed the Code of 1899. The changes are mainly in the line of amendments such as the experience of the last thirteen years has shown to be desirable. The amendments relate to the use of improved steam calorimeters, to sampling coal and determining its moisture, to calorific tests and analysis of coal, to analysis of flue gases, to smoke observations, to determinations of efficiency, and to methods of working out the "heat balance."

The tabular form of presenting the results of the test is somewhat changed and enlarged, and alterations in the text of the Code are made wherever needed. At the same time a second or "short form" of report is added, for use in commercial tests or in cases where it is necessary to give only the principal data and results.

It is beyond the province of the Committee to recommend instruments of particular makers for obtaining the quality of the steam, the calorific value of the fuel, or any other data relating to the trial; but following the practice of the former Committee, individual members have submitted their views (with the approval of the full membership) in an "Appendix to the 1899 Code," signed by their initials. In this appendix are included some of the articles from the appendix to the former Code, which are thought to be of especial value.

In the matter of instruments for determining the calorific value of fuel, it seems desirable that the Committee should make a recommendation which is as specific as present knowledge and circumstances will warrant. It is agreed that some form of calorimeter in which the coal is burned in an atmosphere of oxygen gas is to be preferred, and it is generally held that the most perfect apparatus thus far brought out is the Bomb Calorimeter, originally designed by Berthelot and modified by Mahler and Hempel. Several of these instruments are in use in this country, principally in the laboratories of engineering schools; but the apparatus is complicated and expensive, and it is not probable that many engineers will have the instrument as a part of their equipment for testing boilers. It is

recommended, therefore, that samples of the coal used in testing boilers be sent for determinations of their heating value to a testing laboratory provided with one of these instruments, or with some instrument which shall be proven to be equally good. (Article XVII., Code.)

The Committee approves the conclusions of the 1885 Code to the effect that the standard "unit of evaporation" should be one pound of water at 212 degrees Fahr. evaporated into dry steam of the same temperature. This unit is equivalent to 965.7 British thermal units.

The Committee recommends that, as far as possible, the capacity of a boiler be expressed in terms of the "number of pounds of water evaporated per hour from and at 212 degrees." It does not seem expedient, however, to abandon the widely recognized measure of capacity of stationary or land boilers expressed in terms of "boiler horse-power."

The unit of commercial boiler horse-power adopted by the Committee of 1885 was the same as that used in the reports of the boiler tests made at the Centennial Exhibition in 1876. The Committee of 1885 reported in favor of this standard in language of which the following is an extract:

"Your Committee, after due consideration, has determined to accept the Centennial standard, and to recommend that in all standard trials the commercial horse-power be taken as an evaporation of 30 pounds of water per hour from a feed-water temperature of 100 degrees Fahr. into steam at 70 pounds gauge pressure, which shall be considered to be equal to 34½ units of evaporation; that is, to 34½ pounds of water evaporated from a feed-water temperature of 212 degrees Fahr. into steam at the same temperature. This standard is equal to 33,305 thermal units per hour."

The present Committee accepts the same standard, but reverses the order of two clauses in the statement, and slightly modifies them to read as follows:

The unit of commercial horse-power developed by a boiler shall be taken as 34½ units of evaporation per hour; that is, 34½ pounds of water evaporated per hour from a feed-water temperature of 212 degrees Fahr. into dry steam of the same temperature. This standard is equivalent to 33,317 British thermal units per hour. It is also practically equivalent to an evaporation of 30 pounds of water from a feed-water tem-

perature of 100 degrees Fahr. into steam at 70 pounds gauge pressure.*

The Committee also indorses the statement of the Committee of 1885 concerning the commercial rating of boilers, changing somewhat its wording, so as to read as follows:

A boiler rated at any stated capacity should develop that capacity when using the best coal ordinarily sold in the market where the boiler is located, when fired by an ordinary fireman, without forcing the fires, while exhibiting good economy; and, further, the boiler should develop at least one-third more than the stated capacity when using the same fuel and operated by the same fireman, the full draft being employed and the fires being crowded; the available draft in the flue just beyond the boiler, unless otherwise understood, being not less than $\frac{1}{8}$ inch water column.

Respectfully submitted,

CHAS. E. EMERY,†
WM. KENT,
GEO. H. BARRUS,
CHAS. T. PORTER,
ROBERT H. THURSTON,
ROBERT W. HUNT,
F. W. DEAN,
J. S. COON,
WM. B. POTTER,
} *Committee.*

* According to the tables in Porter's Treatise on the Richards Steam-Engine Indicator, an evaporation of 30 pounds of water from 100 degrees Fahr. into steam at 70 pounds pressure is equal to an evaporation of 34.488 pounds from and at 212 degrees; and an evaporation of 34½ pounds from and at 212 degrees Fahr. is equal to 30.010 pounds from 100 degrees Fahr. into steam at 70 pounds pressure.

The "unit of evaporation" being equivalent to 965.7 thermal units, the commercial horse-power = $34.5 \times 965.7 = 33{,}317$ thermal units.

† The motion for the appointment of this Committee was made by Mr. Barrus in connection with the discussion of Mr. Dean's paper, No. DCL., on "The Efficiency of Boilers," etc. The President of the Society designated Mr. Kent, the chairman of the Committee of 1884, to call the first meeting of the new Committee. At that meeting, on motion of Mr. Kent, Dr. Emery was selected as chairman, and he conducted the preliminary correspondence. The draft of report in the form originally printed and presented for criticism at the Annual Meeting in December, 1897, was prepared by a sub-committee consisting of Messrs. Emery, Porter, Barrus, and Kent. Much of the work of revision of this preliminary draft was done by Dr. Emery a few weeks before his death in June, 1898, and the final revision, bringing the report to its present form, was done by Messrs. Barrus and Kent.

RULES FOR CONDUCTING BOILER TRIALS.

CODE OF 1899.

I. *Determine at the outset* the specific object of the proposed trial, whether it be to ascertain the capacity of the boiler, its efficiency as a steam generator, its efficiency and its defects under usual working conditions, the economy of some particular kind of fuel, or the effect of changes of design, proportion, or operation; and prepare for the trial accordingly. (Appendix II.)

II. *Examine the boiler*, both outside and inside; ascertain the dimensions of grates, heating surfaces, and all important parts; and make a full record, describing the same, and illustrating special features by sketches. The area of heating surface is to be computed from the surfaces of shells, tubes, furnaces, and fireboxes in contact with the fire or hot gases. The outside diameter of water-tubes and the inside diameter of fire-tubes are to be used in the computation. All surfaces below the mean water level which have water on one side and products of combustion on the other are to be considered as water-heating surface, and all surfaces above the mean water level which have steam on one side and products of combustion on the other are to be considered as superheating surface.

III. *Notice the general condition* of the boiler and its equipment, and record such facts in relation thereto as bear upon the objects in view.

If the object of the trial is to ascertain the maximum economy or capacity of the boiler as a steam generator, the boiler and all its appurtenances should be put in first-class condition. Clean the heating surface inside and outside, remove clinkers from the grates and from the sides of the furnace. Remove all dust, soot, and ashes from the chambers, smoke connections, and flues. Close air leaks in the masonry and poorly fitted cleaning doors. See that the damper will open wide and close tight. Test for air leaks by firing a few shovels of smoky fuel and immediately closing the damper, observing the escape of smoke through the crevices, or by passing the flame of a candle over cracks in the brickwork.

IV. *Determine the character of the coal* to be used. For tests of the efficiency or capacity of the boiler for comparison with other boilers the coal should, if possible, be of some kind which is commercially regarded as a standard. For New England

and that portion of the country east of the Allegheny Mountains, good anthracite egg coal, containing not over 10 per cent. of ash, and semi-bituminous Clearfield (Pa.), Cumberland (Md.), and Pocahontas (Va.) coals are thus regarded. West of the Allegheny Mountains, Pocahontas (Va.) and New River (W. Va.) semi-bituminous, and Youghiogheny or Pittsburg bituminous coals are recognized as standards.* There is no special grade of coal mined in the Western States which is widely recognized as of superior quality or considered as a standard coal for boiler testing. Big Muddy lump, an Illinois coal mined in Jackson County, Ill., is suggested as being of sufficiently high grade to answer these requirements in districts where it is more conveniently obtainable than the other coals mentioned above.

For tests made to determine the performance of a boiler with a particular kind of coal, such as may be specified in a contract for the sale of a boiler, the coal used should not be higher in ash and in moisture than that specified, since increase in ash and moisture above a stated amount is apt to cause a falling off of both capacity and economy in greater proportion than the proportion of such increase.

V. *Establish the correctness of all apparatus* used in the test for weighing and measuring. These are:

1. Scales for weighing coal, ashes, and water.

2. Tanks, or water meters for measuring water. Water meters, as a rule, should only be used as a check on other measurements. For accurate work, the water should be weighed or measured in a tank. (Appendices I., IV., VII., VIII.)

3. Thermometers and pyrometers for taking temperatures of air, steam, feed-water, waste gases, etc. (Appendix XXVII.)

4. Pressure gauges, draught gauges, etc. (Appendices XXVIII. to XXX.)

The kind and location of the various pieces of testing apparatus must be left to the judgment of the person conducting the test; always keeping in mind the main object, *i.e.*, to obtain authentic data.

VI. *See that the boiler is thoroughly heated* before the trial to its usual working temperature. If the boiler is new and of a

* These coals are selected because they are about the only coals which possess the essentials of excellence of quality, adaptability to various kinds of furnaces, grates, boilers, and methods of firing, and wide distribution and general accessibility in the markets.

form provided with a brick setting, it should be in regular use at least a week before the trial, so as to dry and heat the walls. If it has been laid off and become cold, it should be worked before the trial until the walls are well heated.

VII. *The boiler and connections* should be proved to be free from leaks before beginning a test, and all water connections, including blow and extra feed pipes, should be disconnected, stopped with blank flanges, or bled through special openings beyond the valves, except the particular pipe through which water is to be fed to the boiler during the trial. During the test the blow-off and feed pipes should remain exposed to view.

If an injector is used, it should receive steam directly through a felted pipe from the boiler being tested.*

If the water is metered after it passes the injector, its temperature should be taken at the point where it leaves the injector. If the quantity is determined before it goes to the injector the temperature should be determined on the suction side of the injector, and if no change of temperature occurs other than that due to the injector, the temperature thus determined is properly that of the feed-water. When the temperature changes between the injector and the boiler, as by the use of a heater or by radiation, the temperature at which the water enters and leaves the injector and that at which it enters the boiler should all be taken. In that case the weight to be used is that of the water leaving the injector, computed from the heat units if not directly measured, and the temperature, that of the water entering the boiler.

Let w = weight of water entering the injector.
x = " " steam " " "
h_1 = heat units per pound of water entering injector.
h_2 = " " " " " steam " "
h_3 = " " " " " water leaving "

Then, $w + x$ = weight of water leaving injector.

$$x = w \frac{h_2 - h_1}{h_2 - h_3}.$$

* In feeding a boiler undergoing test with an injector taking steam from another boiler, or from the main steam pipe from several boilers, the evaporative results may be modified by a difference in the quality of the steam from such source compared with that supplied by the boiler being tested, and in some cases the connection to the injector may act as a drip for the main steam pipe. If it is known that the steam from the main pipe is of the same pressure and quality as that furnished by the boiler undergoing the test, the steam may be taken from such main pipe.

See that the steam main is so arranged that water of condensation cannot run back into the boiler.

VIII. *Duration of the Test.*—For tests made to ascertain either the maximum economy or the maximum capacity of a boiler, irrespective of the particular class of service for which it is regularly used, the duration should be at least 10 hours of continuous running. If the rate of combustion exceeds 25 pounds of coal per square foot of grate surface per hour, it may be stopped when a total of 250 pounds of coal has been burned per square foot of grate.

In cases where the service requires continuous running for the whole 24 hours of the day, with shifts of firemen a number of times during that period, it is well to continue the test for at least 24 hours.

When it is desired to ascertain the performance under the working conditions of practical running, whether the boiler be regularly in use 24 hours a day or only a certain number of hours out of each 24, the fires being banked the balance of the time, the duration should not be less than 24 hours.

IX. *Starting and Stopping a Test.*—The conditions of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure should be the same; the water level the same; the fire upon the grates should be the same in quantity and condition; and the walls, flues, etc., should be of the same temperature. Two methods of obtaining the desired equality of conditions of the fire may be used, viz.: those which were called in the Code of 1885 "the standard method" and "the alternate method," the latter being employed where it is inconvenient to make use of the standard method.*

X. *Standard Method of Starting and Stopping a Test.*—Steam being raised to the working pressure, remove rapidly all the fire from the grate, close the damper, clean the ash pit, and as quickly as possible start a new fire with weighed wood and coal, noting the time and the water level† while

* The Committee concludes that it is best to retain the designations "standard" and "alternate," since they have become widely known and established in the minds of engineers and in the reprints of the Code of 1885. Many engineers prefer the "alternate" to the "standard" method on account of its being less liable to error due to cooling of the boiler at the beginning and end of a test.

† The gauge-glass should not be blown out within an hour before the water level is taken at the beginning and end of a test, otherwise an error in the reading of the water level may be caused by a change in the temperature and density of the water in the pipe leading from the bottom of the glass into the boiler.

the water is in a quiescent state, just before lighting the fire.

At the end of the test remove the whole fire, which has been burned low, clean the grates and ash pit, and note the water level when the water is in a quiescent state, and record the time of hauling the fire. The water level should be as nearly as possible the same as at the beginning of the test. If it is not the same, a correction should be made by computation, and not by operating the pump after the test is completed.

XI. *Alternate Method of Starting and Stopping a Test.*—The boiler being thoroughly heated by a preliminary run, the fires are to be burned low and well cleaned. Note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the water level. Note the time, and record it as the starting time. Fresh coal which has been weighed should now be fired. The ash pits should be thoroughly cleaned at once after starting. Before the end of the test the fires should be burned low, just as before the start, and the fires cleaned in such a manner as to leave a bed of coal on the grates of the same depth, and in the same condition, as at the start. When this stage is reached, note the time and record it as the stopping time. The water level and steam pressures should previously be brought as nearly as possible to the same point as at the start. If the water level is not the same as at the start, a correction should be made by computation, and not by operating the pump after the test is completed.

XII. *Uniformity of Conditions.*—In all trials made to ascertain maximum economy or capacity, the conditions should be maintained uniformly constant. Arrangements should be made to dispose of the steam so that the rate of evaporation may be kept the same from beginning to end. This may be accomplished in a single boiler by carrying the steam through a waste steam pipe, the discharge from which can be regulated as desired. In a battery of boilers, in which only one is tested, the draft may be regulated on the remaining boilers, leaving the test boiler to work under a constant rate of production.

Uniformity of conditions should prevail as to the pressure of steam, the height of water, the rate of evaporation, the thickness of fire, the times of firing and quantity of coal fired at one time, and as to the intervals between the times of cleaning the fires.

The method of firing to be carried on in such tests should be dictated by the expert or person in responsible charge of the test, and the method adopted should be adhered to by the fireman throughout the test.

XIII. *Keeping the Records.*—Take note of every event connected with the progress of the trial, however unimportant it may appear. Record the time of every occurrence and the time of taking every weight and every observation. (Appendices I., IV., V., VI., VII., VIII.)

The coal should be weighed and delivered to the fireman in equal proportions, each sufficient for not more than one hour's run, and a fresh portion should not be delivered until the previous one has all been fired. The time required to consume each portion should be noted, the time being recorded at the instant of firing the last of each portion. It is desirable that at the same time the amount of water fed into the boiler should be accurately noted and recorded, including the height of the water in the boiler, and the average pressure of steam and temperature of feed during the time. By thus recording the amount of water evaporated by successive portions of coal, the test may be divided into several periods if desired, and the degree of uniformity of combustion, evaporation, and economy analyzed for each period. In addition to these records of the coal and the feed water, half hourly observations should be made of the temperature of the feed water, of the flue gases, of the external air in the boiler-room, of the temperature of the furnace when a furnace pyrometer is used, also of the pressure of steam, and of the readings of the instruments for determining the moisture in the steam. A log should be kept on properly prepared blanks containing columns for record of the various observations. (Appendix XXII.)

When the "standard method" of starting and stopping the test is used, the hourly rate of combustion and of evaporation and the horse-power should be computed from the records taken during the time when the fires are in active condition. This time is somewhat less than the actual time which elapses between the beginning and end of the run. The loss of time due to kindling the fire at the beginning and burning it out at the end makes this course necessary.

XIV. *Quality of Steam.*—The percentage of moisture in the steam should be determined by the use of either a throttling or

a separating steam calorimeter. The sampling nozzle should be placed in the vertical steam pipe rising from the boiler. It should be made of $\frac{1}{2}$-inch pipe, and should extend across the diameter of the steam pipe to within half an inch of the opposite side, being closed at the end and perforated with not less than twenty $\frac{1}{8}$-inch holes equally distributed along and around its cylindrical surface, but none of these holes should be nearer than $\frac{1}{2}$ inch to the inner side of the steam pipe. The calorimeter and the pipe leading to it should be well covered with felting. Whenever the indications of the throttling or separating calorimeter show that the percentage of moisture is irregular, or occasionally in excess of three per cent., the results should be checked by a steam separator placed in the steam pipe as close to the boiler as convenient, with a calorimeter in the steam pipe just beyond the outlet from the separator. The drip from the separator should be caught and weighed, and the percentage of moisture computed therefrom added to that shown by the calorimeter. (See Appendices XV. to XVII.)

Superheating should be determined by means of a thermometer placed in a mercury well inserted in the steam pipe. The degree of superheating should be taken as the difference between the reading of the thermometer for superheated steam and the readings of the same thermometer for saturated steam at the same pressure as determined by a special experiment, and not by reference to steam tables.

For calculations relating to quality of steam and corrections for quality of steam, see Appendices XVIII. and XIX.

XV. *Sampling the Coal and Determining its Moisture.*—As each barrow load or fresh portion of coal is taken from the coal pile, a representative shovelful is selected from it and placed in a barrel or box in a cool place and kept until the end of the trial. The samples are then mixed and broken into pieces not exceeding one inch in diameter, and reduced by the process of repeated quartering and crushing until a final sample weighing about five pounds is obtained, and the size of the larger pieces is such that they will pass through a sieve with $\frac{1}{4}$-inch meshes. From this sample two one-quart, air-tight glass preserving jars, or other air-tight vessels which will prevent the escape of moisture from the sample, are to be promptly filled, and these samples are to be kept for subsequent determinations of moisture and of heating value and for chemical analyses. During the

process of quartering, when the sample has been reduced to about 100 pounds, a quarter to a half of it may be taken for an approximate determination of moisture. This may be made by placing it in a shallow iron pan, not over three inches deep, carefully weighing it, and setting the pan in the hottest place that can be found on the brickwork of the boiler setting or flues, keeping it there for at least 12 hours, and then weighing it. The determination of moisture thus made is believed to be approximately accurate for anthracite and semi-bituminous coals, and also for Pittsburg or Youghiogheny coal; but it cannot be relied upon for coals mined west of Pittsburg, or for other coals containing inherent moisture. For these latter coals it is important that a more accurate method be adopted. The method recommended by the Committee for all accurate tests, whatever the character of the coal, is described as follows:

Take one of the samples contained in the glass jars, and subject it to a thorough air-drying, by spreading it in a thin layer and exposing it for several hours to the atmosphere of a warm room, weighing it before and after, thereby determining the quantity of surface moisture it contains. Then crush the whole of it by running it through an ordinary coffee mill adjusted so as to produce somewhat coarse grains (less than $\frac{1}{16}$-inch), thoroughly mix the crushed sample, select from it a portion of from 10 to 50 grams, weigh it in a balance which will easily show a variation as small as 1 part in 1,000, and dry it in an air or sand bath at a temperature between 240 and 280 degrees Fahr. for one hour. Weigh it and record the loss, then heat and weigh it again repeatedly, at intervals of an hour or less, until the minimum weight has been reached and the weight begins to increase by oxidation of a portion of the coal. The difference between the original and the minimum weight is taken as the moisture in the air-dried coal. This moisture test should preferably be made on duplicate samples, and the results should agree within 0.3 to 0.4 of one per cent., the mean of the two determinations being taken as the correct result. The sum of the percentage of moisture thus found and the percentage of surface moisture previously determined is the total moisture. (Appendix XI.)

XVI. *Treatment of Ashes and Refuse.*—The ashes and refuse are to be weighed in a dry state. If it is found desirable to show the principal characteristics of the ash, a sample should be subjected to a proximate analysis and the actual amount

of incombustible material determined. For elaborate trials a complete analysis of the ash and refuse should be made.

XVII. *Calorific Tests and Analysis of Coal.*—The quality of the fuel should be determined either by heat test or by analysis, or by both.

The rational method of determining the total heat of combustion is to burn the sample of coal in an atmosphere of oxygen gas, the coal to be sampled as directed in Article XV. of this code. (See Appendices XIII. and XIV.)

The chemical analysis of the coal should be made only by an expert chemist. The total heat of combustion computed from the results of the ultimate analysis may be obtained by the use of Dulong's formula (with constants modified by recent determinations), viz.: $14{,}600\ C + 62{,}000\left(H - \frac{O}{8}\right) + 4{,}000\ S$, in which C, H, O, and S refer to the proportions of carbon, hydrogen, oxygen, and sulphur respectively, as determined by the ultimate analysis.*

It is desirable that a proximate analysis should be made, thereby determining the relative proportions of volatile matter and fixed carbon. These proportions furnish an indication of the leading characteristics of the fuel, and serve to fix the class to which it belongs. (Appendix XII.) As an additional indication of the characteristics of the fuel, the specific gravity should be determined.

XVIII. *Analysis of Flue Gases.*—The analysis of the flue gases is an especially valuable method of determining the relative value of different methods of firing, or of different kinds of furnaces. In making these analyses great care should be taken to procure average samples—since the composition is apt to vary at different points of the flue (Appendix XXXI.). The composition is also apt to vary from minute to minute, and for this reason the drawings of gas should last a considerable period of time. Where complete determinations are desired, the analyses should be intrusted to an expert chemist. For approximate determinations the Orsat† or the Hempel‡ apparatus may be used by the engineer. (See Appendix XXXIII.)

* Favre and Silberman give 14,544 B.T.U. per pound carbon; Berthelot 14,647 B.T.U. Favre and Silberman give 62,032 B.T.U. per pound hydrogen; Thomsen 61,816 B.T.U.

† See R. S. Hale's paper on "Flue Gas Analysis," *Transactions*, vol. xviii., p. 901.

‡ See Hempel's "Methods of Gas Analysis" (Macmillan & Co.).

For the continuous indication of the amount of carbonic acid present in the flue gases, an instrument may be employed which shows the weight of the sample of gas passing through it. (Appendix XXXIX.)

XIX. *Smoke Observations.*—It is desirable to have a uniform system of determining and recording the quantity of smoke produced where bituminous coal is used. The system commonly employed is to express the degree of smokiness by means of percentages dependent upon the judgment of the observer. The Committee does not place much value upon a percentage method, because it depends so largely upon the personal element, but if this method is used, it is desirable that, so far as possible, a definition be given in explicit terms as to the basis and method employed in arriving at the percentage. The actual measurement of a sample of soot and smoke by some form of meter is to be preferred. (See Appendices XXXIV. and XXXV.)

XX. *Miscellaneous.*—In tests for purposes of scientific research, in which the determination of all the variables entering into the test is desired, certain observations should be made which are in general unnecessary for ordinary tests. These are the measurement of the air supply, the determination of its contained moisture, the determination of the amount of heat lost by radiation, of the amount of infiltration of air through the setting, and (by condensation of all the steam made by the boiler) of the total heat imparted to the water.

As these determinations are rarely undertaken, it is not deemed advisable to give directions for making them.

XXI. *Calculations of Efficiency.*—Two methods of defining and calculating the efficiency of a boiler are recommended. They are:

1. Efficiency of the boiler $= \frac{\text{Heat absorbed per lb. combustible}}{\text{Calorific value of 1 lb. combustible}}$

2. Efficiency of the boiler and grate $= \frac{\text{Heat absorbed per lb. coal}}{\text{Calorific value of 1 lb. coal}}$

The first of these is sometimes called the efficiency based on combustible, and the second the efficiency based on coal. The first is recommended as a standard of comparison for all tests, and this is the one which is understood to be referred to when the word "efficiency" alone is used without qualification. The second, however, should be included in a report of a test, together with the first, whenever the object of the test is to determine the efficiency of the boiler and furnace together with the

grate (or mechanical stoker), or to compare different furnaces, grates, fuels, or methods of firing.

The heat absorbed per pound of combustible (or per pound coal) is to be calculated by multiplying the equivalent evaporation from and at 212 degrees per pound combustible (or coal) by 965.7. (Appendix XX.)

XXII. *The Heat Balance.*—An approximate "heat balance," or statement of the distribution of the heating value of the coal among the several items of heat utilized and heat lost may be included in the report of a test when analyses of the fuel and of the chimney gases have been made. It should be reported in the following form:

HEAT BALANCE, OR DISTRIBUTION OF THE HEATING VALUE OF THE COMBUSTIBLE.

Total Heat Value of 1 lb. of Combustible..... .....B. T. U.

		B. T. U.	Per Cent.
1.	Heat absorbed by the boiler = evaporation from and at 212 degrees per pound of combustible × 965.7.		
2.	Loss due to moisture in coal = per cent. of moisture referred to combustible ÷ 100 × [(212 − t) + 966 + 0.48 (T − 212)] (t = temperature of air in the boiler-room, T = that of the flue gases)		
3.	Loss due to moisture formed by the burning of hydrogen = per cent. of hydrogen to combustible ÷ 100 × 9 × [(212 − t) + 966 + 0.48 (T − 212)].		
4.*	Loss due to heat carried away in the dry chimney gases = weight of gas per pound of combustible × 0.24 × (T − t).		
5.†	Loss due to incomplete combustion of carbon = $\frac{CO}{CO_2 + CO}$ × $\frac{\text{per cent. C in combustible}}{100}$ × 10,150.		
6.	Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation, and unaccounted for. (Some of these losses may be separately itemized if data are obtained from which they may be calculated.)		
	Totals.....		100.00

*The weight of gas per pound of carbon burned may be calculated from the gas analyses as follows:

Dry gas per pound carbon = $\frac{11\ CO_2 + 8\ O + 7\ (CO + N)}{3\ (CO_2 + CO)}$, in which CO_2, CO, O, and N are the percentages by volume of the several gases. As the sampling and analyses of the gases in the present state of the art are liable to considerable errors, the result of this calculation is usually only an approximate one. The heat balance itself is also only approximate for this reason, as well as for the fact that it is not possible to determine accurately the percentage of unburned hydrogen or hydrocarbons in the flue gases. (See Appendix XXXII.)

The weight of dry gas per pound of combustible is found by multiplying the dry gas per pound of carbon by the percentage of carbon in the combustible, and dividing by 100.

†CO_2 and CO are respectively the percentage by volume of carbonic acid and carbonic oxide in the flue gases. The quantity 10,150 = Number of heat units generated by burning to carbonic acid one pound of carbon contained in carbonic oxide.

XXIII. *Report of the Trial.*—The data and results should be reported in the manner given in either one of the two following

tables, omitting lines where the tests have not been made as elaborately as provided for in such tables. Additional lines may be added for data relating to the specific object of the test. The extra lines should be classified under the headings provided in the tables, and numbered as per preceding line, with sub letters *a*, *b*, etc. The Short Form of Report, Table No. 2, is recommended for commercial tests and as a convenient form of abridging the longer form for publication when saving of space is desirable. For elaborate trials, it is recommended that the full log of the trial be shown graphically, by means of a chart. (Appendix XXXVIII.)

TABLE NO. 1.

DATA AND RESULTS OF EVAPORATIVE TEST,

Arranged in accordance with the Complete Form advised by the Boiler Test Committee of the American Society of Mechanical Engineers. Code of 1899.

Made by..... .....of.....boiler at.....to determine.....
.....
Principal conditions governing the trial .....
.....
.....
Kind of fuel *.....
Kind of furnace .....
State of the weather.....

Method of starting and stopping the test ("standard" or "alternate," Art. X. and XI., Code).....

1. *Date of trial* .....
2. *Duration of trial*..... hours.

Dimensions and Proportions.

(A complete description of the boiler, and drawings of the same if of unusual type, should be given on an annexed sheet. (See Appendix X.)

3. *Grate surface* .....*width*.....*length*.....*area*..... sq. ft.
4. Height of furnace..... ins.
5. Approximate width of air spaces in grate..... in.
6. Proportion of air space to whole grate surface..... per cent.
7. *Water-heating surface*..... sq. ft.
8. *Superheating surface*..... "
9. Ratio of water-heating surface to grate surface..... — to 1.
10. Ratio of minimum draft area to grate surface ..... 1 to —

* The items printed in italics correspond to the items in the "Short Form of Code."

Average Pressures.

11.	*Steam pressure by gauge*	lbs. per sq. in.
12.	*Force of draft between damper and boiler*	ins. of water
13.	Force of draft in furnace	" "
14.	Force of draft or blast in ashpit	" "

Average Temperatures.

15.	Of external air	deg.
16.	Of fireroom	"
17.	Of steam	"
18.	Of feed water entering heater	"
19.	Of feed water entering economizer	"
20.	*Of feed water entering boiler*	"
21.	*Of escaping gases from boiler*	"
22.	Of escaping gases from economizer	"

Fuel.

23.	Size and condition	
24.	Weight of wood used in lighting fire	lbs.
25.	*Weight of coal as fired* *	"
26.	*Percentage of moisture in coal* †	per cent.
27.	*Total weight of dry coal consumed*	lbs.
28.	*Total ash and refuse*	"
29.	Quality of ash and refuse	
30.	Total combustible consumed	lbs.
31.	*Percentage of ash and refuse in dry coal*	per cent.

Proximate Analysis of Coal.

(App. XII.)

		Of Coal. per cent.	Of Combustible. per cent.
32.	Fixed carbon	"	"
33.	Volatile matter	"	——
34.	Moisture	"	——
35.	Ash		
		100 per cent.	100 per cent.
36.	Sulphur, separately determined	"	"

* Including equivalent of wood used in lighting the fire, not including unburnt coal withdrawn from furnace at times of cleaning and at end of test. One pound of wood is taken to be equal to 0.4 pound of coal, or, in case greater accuracy is desired, as having a heat value equivalent to the evaporation of 6 pounds of water from and at 212 degrees per pound. (6 × 965.7 = 5,794 B. T. U.) The term "as fired" means in its actual condition, including moisture.

† This is the total moisture in the coal as found by drying it artificially, as described in Art. XV. of Code.

Ultimate Analysis of Dry Coal.

(Art. XVII., Code.)

	Of Coal.	Of Combustible.
37. Carbon (C)	per cent.	per cent.
38. Hydrogen (H)	"	"
39. Oxygen (O)	"	"
40. Nitrogen (N)	"	"
41. Sulphur (S)	"	"
42. Ash	"	—
	100 per cent.	100 per cent.
43. Moisture in sample of coal as received	"	"

Analysis of Ash and Refuse.

44. Carbon	per cent.
45. Earthy matter	"

Fuel per Hour.

46. *Dry coal consumed per hour*	lbs.
47. Combustible consumed per hour	"
48. *Dry coal per square foot of grate surface per hour*	"
49. Combustible per square foot of water-heating surface per hour.	"

Calorific Value of Fuel.

(Art. XVII., Code.)

50. *Calorific value by oxygen calorimeter, per lb. of dry coal*	B.T.U.
51. *Calorific value by oxygen calorimeter, per lb. of combustible*	"
52. Calorific value by analysis, per lb. of dry coal *	"
53. Calorific value by analysis, per lb. of combustible	"

Quality of Steam.

(App. XV. to XIX.)

54. *Percentage of moisture in steam*	per cent.
55. *Number of degrees of superheating*	deg.
56. Quality of steam (dry steam = unity). (For exact determination of the factor of correction for quality of steam see Appendix XVIII.)	

Water.

(App. I., IV., VII., VIII.)

57. *Total weight of water fed to boiler* †	lbs.
58. Equivalent water fed to boiler from and at 212 degrees	"
59. *Water actually evaporated, corrected for quality of steam*	"

* See formula for calorific value under Article XVII. of Code.

† Corrected for inequality of water level and of steam pressure at beginning and end of test.

60. Factor of evaporation *..... lbs.
61. Equivalent water evaporated into dry steam from and at 212 degrees. † (Item 59 × Item 60.)..... "

Water per Hour.

62. *Water evaporated per hour, corrected for quality of steam* ..... "
63. *Equivalent evaporation per hour from and at* 212 *degrees* †..... "
64. *Equivalent evaporation per hour from and at* 212 *degrees per square foot of water-heating surface* †..... "

Horse-Power.

65. *Horse-power developed.* (34½ *lbs. of water evaporated per hour into dry steam from and at* 212 *degrees, equals one horse-power*) ‡..... H. P.
66. *Builders' rated horse-power*..... "
67. *Percentage of builders' rated horse-power developed*..... per cent.

Economic Results.

68. *Water apparently evaporated under actual conditions per pound of coal as fired.* (*Item* 57 ÷ *Item* 25.)..... lbs.
69. *Equivalent evaporation from and at* 212 *degrees per pound of coal as fired.* † (*Item* 61 ÷ *Item* 25.)..... "
70. *Equivalent evaporation from and at* 212 *degrees per pound of dry coal.* † (*Item* 61 ÷ *Item* 27.)..... "
71. *Equivalent evaporation from and at* 212 *degrees per pound of combustible.* † (*Item* 61 ÷ *Item* 30.)..... "

(If the equivalent evaporation, Items 69, 70, and 71, is not corrected for the quality of steam, the fact should be stated).

Efficiency.

(Art. XXI., Code.)

72. *Efficiency of the boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of one lb. of combustible* §.... per cent.
73. *Efficiency of boiler, including the grate; heat absorbed by the boiler, per lb. of dry coal, divided by the heat value of one lb. of dry coal*..... "

---

* Factor of evaporation $= \frac{H-h}{965.7}$, in which H and h are respectively the total heat in steam of the average observed pressure, and in water of the average observed temperature of the feed.

† The symbol "U. E." meaning "Units of Evaporation," may be conveniently substituted for the expression "Equivalent water evaporated into dry steam from and at 212 degrees," its definition being given in a foot-note.

‡ Held to be the equivalent of 30 lbs. of water per hour evaporated from 100 degrees Fahr. into dry steam at 70 lbs. gauge pressure. (See Introduction to Code.)

§ In all cases where the word combustible is used, it means the coal without moisture and ash, but including all other constituents. It is the same as what is called in Europe "coal dry and free from ash."

Cost of Evaporation.

74. *Cost of coal per ton of —— lbs. delivered in boiler room*..... $
75. Cost of fuel for evaporating 1,000 lbs. of water under observed conditions..... $
76. *Cost of fuel used for evaporating* 1,000 *lbs. of water from and at* 212 *degrees*..... $

Smoke Observations.

(App. XXXIV. and XXXV.)

77. Percentage of smoke as observed..... per cent.
78. Weight of soot per hour obtained from smoke meter..... ounces.
79. Volume of soot per hour obtained from smoke meter..... cub. in.

Methods of Firing.

80. Kind of firing (spreading, alternate, or coking).....
81. Average thickness of fire.....
82. Average intervals between firings for each furnace during time when fires are in normal condition.....
83. Average interval between times of levelling or breaking up....

Analyses of the Dry Gases.

84. Carbon dioxide (CO_2)..... per cent.
85. Oxygen (O)..... "
86. Carbon monoxide (CO)..... "
87. Hydrogen and hydrocarbons..... "
88. Nitrogen (by difference) (N)..... "

100 per cent.

TABLE NO. 2.

DATA AND RESULTS OF EVAPORATIVE TEST,

Arranged in accordance with the Short Form advised by the Boiler Test Committee of the American Society of Mechanical Engineers. Code of 1899.

Made by.....on.....boiler, at.....to determine.....
Kind of fuel.....
Kind of furnace.....
Method of starting and stopping the test ("standard" or "alternate," Art. X. and XI., Code).....

Grate surface..... sq. ft.
Water-heating surface..... "
Superheating surface..... "

Total Quantities.

1. Date of trial.....
2. Duration of trial..... hours.
3. Weight of coal as fired *..... lbs.
4. Percentage of moisture in coal *..... per cent.
5. Total weight of dry coal consumed..... lbs.
6. Total ash and refuse..... "
7. Percentage of ash and refuse in dry coal..... per cent.

* See foot-notes of Complete Form.

8. Total weight of water fed to the boiler *	lbs.
9. Water actually evaporated, corrected for moisture or superheat in steam	"
10. Equivalent water evaporated into dry steam from and at 212 degrees *	"

Hourly Quantities.

11. Dry coal consumed per hour	lbs.
12. Dry coal per square foot of grate surface per hour	"
13. Water evaporated per hour corrected for quality of steam	"
14. Equivalent evaporation per hour from and at 212 degrees *	"
15. Equivalent evaporation per hour from and at 212 degrees per square foot of water-heating surface *	"

Average Pressures, Temperatures, etc.

16. Steam pressure by gauge	lbs. per sq. in.
17. Temperature of feed water entering boiler	deg.
18. Temperature of escaping gases from boiler	"
19. Force of draft between damper and boiler	ins. of water.
20. Percentage of moisture in steam, or number of degrees of superheating	per cent. or deg.

Horse-Power.

21. Horse-power developed (Item 14 ÷ 34½) *	H. P.
22. Builders' rated horse-power	"
23. Percentage of builders' rated horse-power developed	per cent.

Economic Results.

24. Water apparently evaporated under actual conditions per pound of coal as fired. (Item 8 ÷ Item 3)	lbs.
25. Equivalent evaporation from and at 212 degrees per pound of coal as fired.* (Item 10 ÷ Item 3)	"
26. Equivalent evaporation from and at 212 degrees per pound of dry coal.* (Item 10 ÷ Item 5)	"
27. Equivalent evaporation from and at 212 degrees per pound of combustible.* [Item 10 ÷ (Item 5 − Item 6)]	"
(If Items 25, 26, and 27 are not corrected for quality of steam, the fact should be stated.)	

Efficiency.

28. Calorific value of the dry coal per pound	B. T. U.
29. Calorific value of the combustible per pound	"
30. Efficiency of boiler (based on combustible) *	per cent.
31. Efficiency of boiler, including grate (based on dry coal)	"

Cost of Evaporation.

32. Cost of coal per ton of —— lbs. delivered in boiler-room	$
33. Cost of coal required for evaporating 1,000 pounds of water from and at 212 degrees	$

* See foot-notes of Complete Form.

APPENDICES TO CODE OF 1899.

Appendix I.

RELATIVE WEIGHTS OF WATER AND FUEL.

The elaborate directions and multiplicity of details provided for in the foregoing Code should not divert the minds of amateurs from the fact that the principal elements to be ascertained in a boiler test are the weight of water evaporated and the weight of the fuel required to produce such evaporation. If the Code be scanned closely with this thought in mind, it will be found that many of the elaborate provisions are intended to secure accuracy in determining these important elements. It is true that there are provisions embodied which do not refer directly thereto, but it is necessary that all available data be obtained so that comparisons can be made with the performances of other boilers, for the purpose of adjusting contracts, for general information, as a guide in the selection of fuel, or for improvements in the future.

Moreover, the determination of the two primary elements, to wit: the weights of water and of coal, are not as easy as would seem to an amateur. Many of the older members of the profession have again and again seen boiler tests conducted by inventors and manufacturers who supposed they were obtaining honest reports from their employees, without realizing a trait of human nature which actuates a man whose livelihood depends upon the success of another. Some workmen will make the results come out as they suppose their employers wish them, and if there is any coal to be had in the vicinity that has not been weighed, it will be purloined, a shovelful at a time; and if men of this class are expected to tally the number of tanks of water fed into a boiler, although instructed to be strictly honest and accurate, there will a doubt arise in their minds whether a tally has been made or not, and another tally be made under the influence of such doubt. It is therefore necessary to call the attention of amateurs and young engineers to checks which have been provided to prevent errors in weighing or tallying. It is urged that Article XIII. and other provisions of the Code be particularly studied in connection with the subsequent remarks of different members of the profession, contained particularly in Appendices III., IV., V., VI., VII.,

VIII. It will be found that all agree that the coal should be weighed and water measured or weighed at practically regular intervals, and that in every case the *time* be put down when a bucket of coal is dumped or a tank of water let down, when, by simple reference to the clock, all disputes as to neglected tallies will be eliminated. C. E. E.

APPENDIX II.*

OBJECT OF THE TEST.

In preparing for and conducting trials of steam boilers, the specific object of the proposed trial should be clearly defined and steadily kept in view.

1. If it be to determine the efficiency of a given style of boiler or of boiler setting under normal conditions, the boiler, brickwork, grates, dampers, flues, pipes, in short, the whole apparatus should be carefully examined and accurately described, and any variation from a normal condition should be remedied if possible, and, if irremediable, clearly described and pointed out.

2. If it be to ascertain the condition of a given boiler or set of boilers with a view to the improvement of whatever may be faulty, the conditions actually existing should be accurately observed and clearly described.

3. If the object be to determine the relative value of two or more kinds of coal, or the actual value of any kind, exact equality of conditions should be maintained if possible, or, where that is not practicable, all variations should be duly allowed for.

4. Only one variable should be allowed to enter into the problem; or, since the entire exclusion of disturbing variations cannot usually be effected, they should be kept as closely as possible within narrow limits, and allowed for with all possible accuracy.

J. C. H.

APPENDIX III.

GENERAL OBSERVATIONS.

All observations are to be made by the expert, either personally or by his assistants. No statement of any kind is to be

* This and several other Appendices are copied from the report of the Committee of 1885. (See List of Appendices, p. 111.) Those signed J. C. H. were contributed to the Code of 1885 by the late John C. Hoadley.

received from the owner or persons in charge of the boiler. All possibility of anything that would falsify the results must be closely guarded against; all pipes not used must be taken away or blank flanges inserted.

The two great points that are to be determined in every test of a steam boiler, whatever the special and precise purpose of such test may be, are the pounds of fuel burned and the pounds of water evaporated.

To arrive at these we need to know, first, the pounds of fuel put into the furnace, and, second, the pounds of water fed into the boiler.

To ascertain these facts with certainty is the fundamental requisite in all cases. The possibility of an error in either of these respects throws doubt upon all the results or indications of the test. The coal supplied to the furnace and the water fed to the boiler should, therefore, each be ascertained in a manner that proves its own correctness and excludes doubt.

All tests of this nature are properly regarded with suspicion. I often myself read of tests and results that I put no faith in, and the same must be true of every one who is experienced in this matter. I am therefore strenuous on this point, that a system of firing and a system of measuring the feed-water should be employed that will prove the correctness of the record, and, if errors are made, will clearly expose them.

If possible the steam generated should be condensed by passing it through a surface condenser, where it is cooled by a strong current of water in a closed chamber. By this means the number of thermal units added may be ascertained with precision.

A boiler test cannot be conducted properly when it is complicated by being combined with an engine test.

C. T. P.

Appendix IV.

PRECAUTIONS TO BE OBSERVED IN MAKING A BOILER TEST.

It should be steadily kept in mind that the principal observations to be made are the quantities of coal consumed and of water evaporated. If these quantities are ascertained ac-

curately, and the conditions made the same at the beginning and end of the test, the most important requisites of a boiler trial will be secured. Other observations have their value both for scientific and practical purposes, but are in most cases subsidiary.

Boiler tests are often undertaken with insufficient apparatus and assistance. It is possible for a single person to test one boiler, or even several in a battery, but it requires a great deal of labor to do so, and in many cases such person would be so fatigued as to be liable to make a simple error vitiating the results. He would, moreover, at no time be able to give proper oversight to the test, so as to prevent accidental or unauthorized interferences. It is very desirable, in fact almost indispensable, that an assistant be detailed to weigh the coal, and another to weigh or measure the water; if calorimeter tests are to be undertaken, still another assistant should be provided. The engineer in charge is then left free to oversee the work of all, and relieve either temporarily when necessary. Engineers are frequently called upon to make boiler trials in connection with parties whose interests are antagonistic to a fair test, and frequently the voluntary assistance of busybodies is likely to produce errors in the results. It is therefore essential to have trustworthy assistants, and those of sufficient calibre not to be confused by interested parties, who will frequently endeavor in the most plausible manner to make out that a certain measure of coal has been already tallied, or that a certain tank of water has not been tallied.

In the first engine trials at the American Institute Exhibition (1869), in the Centennial boiler trials (1876), and since in private trials respecting performance of boilers as between the contractor and purchaser, the writer has arranged for both interests to take the data at the same moment, with instructions, if agreement could not be had, that the difference be at once referred to him.

In weighing the coal, the barrow or vessel used should be balanced on a scale and then filled to a certain definite weight. The laborer will soon learn to fill a vessel to the same weight within a few pounds by counting the number of shovels thrown in, when the change of a lump or two to or from a small box alongside the scale will balance it.

The water may be measured in one tank by filling it to one

mark and pumping down to another, but this involves stopping the pump when filling the tank, thereby failing to maintain uniformity of conditions. Two tanks arranged so that each can be filled and emptied alternately are much better. A still better plan is to have a settling tank to pump from and a measuring tank which is emptied into it, and this plan is improved by setting the measuring tank on a scale, and actually weighing the water. For large operations three tanks are necessary: a lower tank to pump from, and two measuring tanks, one of which is filling while the other is being emptied. The writer has made several double measuring tanks with a horizontal section like the figure "8," there being a partition between the two tanks lower than the rim of the tanks. Water is conducted at will in either of the two tanks by a pipe swinging over the partition. One tank is allowed to fill until the water in it overflows into the other (which has been emptied and the cock shut), when the filling pipe is shifted into the empty tank, and as soon as the water level subsides in the full one the water in that tank is allowed to flow out, the cock shut before the other tank is filled, and the operation repeated.

A simple tally should never be trusted. Nothing seems more reliable to an inexperienced observer than to mark 1, 2, 3, 4, with a diagonal cross mark for 5; but when there are waits of several minutes between the marks, and several operations performed after a tally is made, there will be confusion in the mind whether or not the tally has been actually made. The tallies both of weights of coal and of tanks of water should be written on separate lines, the time noted opposite each, and the records always made at the beginning or termination of some particular operation; for instance, in weighing coal at the time only when the barrel or bucket is dumped on the fire-room floor. It is desirable to have a number of coincident records of coal and water throughout the trial, so that in case of accident it may be held to have ended at one of such times. The uniformity of the operations may also be tested in this way from time to time. For this reason it will be found convenient to fire from a wheelbarrow set on a scale and to have a float or water-gauge connected with the tank from which the water is pumped; by which means the coal and water used may, in an evident way, be ascertained for any desired interval.

C. E. E.

Appendix V.

WEIGHING THE COAL.

Where practicable, a box consisting of sides, back, and bottom, capable of holding 500 pounds of coal for each boiler having 25 square feet fire-grate area, and in proportion for larger grates, should be placed on scales conveniently located for shovelling from it upon the fire grate.

The exact time of weighing each charge of, say, 500 pounds should be noted and the net weight, whatever it be, set down. The box should be balanced by a fixed counterpoise, so that the readings of the scale beam may be net pounds of coal.

On the instant of closing the fire door after each firing, the weight should be taken and the exact time noted as well as the weight. The box should be completely emptied each time, and the accuracy of the counterpoise observed, and, if necessary, adjusted. The differences of weight at each firing will give the several quantities fired; the differences of time will give the intervals in minutes and seconds between successive firings; and the differences of time between the successive charges—500 pounds, more or less—on the scales will afford a check on the record of the firing. A chart or diagram should be plotted from the figures, which will clearly show the degree of regularity with which firing has been carried on, and reveal any omission or error.

J. C. H.

Appendix VI.

WEIGHING THE COAL.

I would recommend that on a test no coal be brought into the furnace room except as follows:

A barrow to be employed, and be loaded each time at the coal pile with an equal amount, say 600 pounds, of coal, weighed on platform scales at the pile. The time when it is thus wheeled into the furnace-room to be noted. The barrow to be wheeled upon another platform scale before the furnace for the following purpose:

In separate columns, the times of charging the furnace to be noted, and the reading of the scales after each charging. The

coal to be shovelled from the barrow directly into the furnace.

Now here the log would show at once, by the great inequality of the intervals, if a barrow-load of coal had been added or omitted, and the weights charged on the fire would check the barrow-loads, and should also show the rate of firing.

No other coal being convenient to the furnace, reasonable watching will give assurance that none is surreptitiously added to the fire. C. T. P.

Appendix VII.

WEIGHING THE WATER.

The best way is to have two tanks capable of holding 1,200 to 1,800 pounds—say 20 to 30 cubic feet; or two weighing tanks and one feeding tank, 144 to 216 gallons, each placed on a pair of scales, to be filled and emptied alternately. To avoid suspicion of leakage of stop-cocks, it is better to draw out the water by a flexible pipe or suction hose put alternately into the two tanks. The time of each weighing of each tank, to be designated as tank No. 1 and tank No. 2, should be accurately noted, and a method of checking the weighings by a diagram or chart, as in respect to the coal, should be adopted. J. C. H.

Appendix VIII.

MEASURING THE FEED WATER.

I would recommend that on all tests of any magnitude the water be fed to the boilers from a single tank of known capacity. That the tank be always filled so as to overflow while the feed pump is stopped, and also the communication to it is closed.

That the inlet pipe shall terminate above the tank so that its orifice is always visible. That after the supply has been shut off, and the overflow has ceased, the communication to the feed pump be opened and the pump be started. That the water be drawn down to a point that is determined by a line on a graduated rod attached to a float that has been well painted so as not to absorb the water; and that then the pump be stopped, communication with it be closed, and the tank be refilled.

The time of starting the pump each time to be carefully noted.

The regularity of the intervals would leave no room for doubt as to the number of tanks that had been emptied. The watch of opposite interests would insure the accuracy of the line at which the pump is stopped each time, and at which the test was closed.

C. T. P.

Appendix IX.

KEEPING TIME OF OBSERVATIONS.

All time-keepers should be set at the start, and compared at the close; a gong should be used to give a signal for all observations designed to be synchronous and isochronous, in order that such observations may be conveniently arranged.

J. C. H.

Appendix X.

DESCRIPTION OF BOILER.

The report should include a complete description of the boiler, which, for special boilers, should be written out at length, but generally can conveniently be presented in tabular form substanially as follows:

Type of boiler.
Diameter of shell.
Length of shell.
Number of tubes.
Diameter " "
Length " "
Diameter of steam drum.
Width of furnace.
Length of furnace.
Kind of grate bars.
Width of air spaces.
Ratio of area of grate to area of air spaces.
Area of chimney.
Height of chimney.
Length of flues connecting to chimney.
Area " " " " "

GOVERNING PROPORTIONS.

Grate surface.

Heating surface { Water. / Steam. / Total.

Area of draft through or between tubes.

Ratio grate to heating surface.

" draft area to grate.

" " " " total heating surface.

Water space.

Steam space.

Ratio grate to water space.

" " " steam space.

C. E. E.

APPENDIX XI.

DETERMINING THE MOISTURE IN COAL.

Until recently two methods of determining moisture in coal have been in common use—first, the one usually adopted in boiler testing, which consists in drying a large sample, fifty pounds or more, in a shallow pan placed over the boiler or flue; second, the method usually followed by chemists, of drying a one-gram sample of pulverized coal at 212 degrees Fahr., or a little above, for an hour, or until constant weight is obtained. Both methods are liable to large errors. In the first method the temperature at which the drying takes place is uncertain, and there is no means of knowing whether the temperature obtained is sufficient to drive off the moisture which is held by capillary force or other attraction within the lumps of coal, which, at least in case of bituminous coals, seem to be as porous as wood, and as capable of absorbing moisture from the atmosphere. The second method is liable to greater errors in sampling than the first, and during the process of fine crushing and passing through sieves a considerable portion of the moisture is apt to be removed by air-drying. In an extensive series of boiler tests made by the writer in the summer of 1896, it became necessary to find more accurate means of determining moisture than either of those above described. It was found that by repeated heating at gradually increasing temperatures

from 212 degrees up to 300 degrees or over, and weighing at intervals of an hour or more, that the weight of coal continually decreased until it became nearly constant, and then a very slight increase took place, which increase became greater on further repeated heatings to temperatures above 250 degrees. It has often been stated that if coal is heated above 212 degrees Fahr. volatile matter will be driven off; but repeated tests on seventeen different varieties of coal mined in western Pennsylvania, Ohio, Indiana, Illinois, and Kentucky invariably showed a gradual decrease of weight to a minimum, followed by the increase. as stated above, and in no single case was there any perceptible odor or other indication of volatile matter passing off below a temperature of 350 degrees. The fact that no volatile matter was given off was further proved by heating the coal in a glass retort and catching the vapor driven off in a bottle filled with water and inverted in a basin; the air displaced from the retort by expansion due to the heating displacing the water in the bottle. When the retort was cooled, after being heated to 350 degrees in an oil bath, the air thus expanded contracted, and returned from the bottle to the retort, leaving the bottle full of water as at the beginning of the heating, showing that no gas had been given off, except possibly such exceedingly small amount as might be absorbed by the water. The method described in Section XV. of the report was then adopted as the best available method of determining the moisture in these coals. Its accuracy was further checked by other methods, as follows: 1. A lump of Illinois coal which had been found by heating to 300 degrees to contain 14 per cent. of moisture was exposed to the air in a closet for two months, and it gradually reabsorbed from the atmosphere all the moisture that had been driven off. 2. Another sample of the same coal was placed in a dessicator with concentrated sulphuric acid, and it lost practically the same percentage of moisture in two months that was given off by the heating. 3. Seven other samples of different coals were similarly treated for six weeks, and all of them lost within about one per cent. of the amount that duplicate samples had lost by heating, and the difference in each case was lost by a single heating for an hour to 280 degrees.

The new method of drying and its results were communicated by the writer to Prof. R. C. Carpenter of Cornell University, shortly after they were made, and he thereupon began experi-

menting with the method, and fully confirmed the writer's conclusions. In a letter dated May 18, 1897, he says: "We have investigated the moisture question, and find that in all the samples tested, some four or five in number, there is no appreciable loss between temperatures of 250 and 350 degrees; at least, the loss is less than our means of weighing." In his paper on "Hygrometric Properties of Coals," presented at the Hartford meeting (*Transactions*, vol. xviii., p. 948), he says:

"With the most volatile coals there is no sensible loss of weight due to the driving off of volatile matter under a temperature of 380 degrees Fahr., and with anthracite coal there is no sensible loss under a temperature of 700 degrees Fahr."

W. K.

Appendix XII.

PROXIMATE ANALYSES OF COAL.

For comparing the proximate analyses of different coals, it is desirable that they should be reported in a uniform style. The four constituents determined by heating in a crucible should be given and their sum should equal 100 per cent. When sulphur is determined it should be stated separately, and it should not be subtracted from the fixed carbon and the volatile matter (half from each, as is the custom of some chemists, or 0.4 from one and 0.6 from the other, as is the custom of others), since it cannot be known what proportion of sulphur escapes from the crucible with the volatile matter and what proportion is burned with the fixed carbon. The carbon ratio—that is, the ratio of fixed carbon to volatile matter—should also be stated, preferably as percentages of their sum, thus: 40 per cent. volatile matter, 60 per cent. fixed carbon, which is equivalent to a carbon ratio of $1\frac{1}{2}$.

The proximate analysis is a most valuable means of identifying the general character of the coal. First, the amount of volatile matter, expressed as a percentage of the combustible, distinguishes between the anthracite, the semi-bituminous, and the bituminous coals. Second, among the bituminous coals the moisture is an important guide to the character of the coal, Third, the ash is also a criterion of the coal's value. Fourth, the sulphur taken in connection with the ash is also an indication of the value of the fuel, as high sulphur generally is found in a

coal which clinkers badly, and with which it is difficult to obtain the rated capacity of a boiler.

W. K.

Appendix XIII.

COAL CALORIMETER.

The coal calorimeter which the writer employs is that described in a paper on "A Coal Calorimeter," read at the Chicago meeting in 1893, and published in the *Transactions*, vol. xiv., page 816. The details of the instrument are shown in the accompanying cut (Fig. 1). It consists of a glass beaker 5 inches

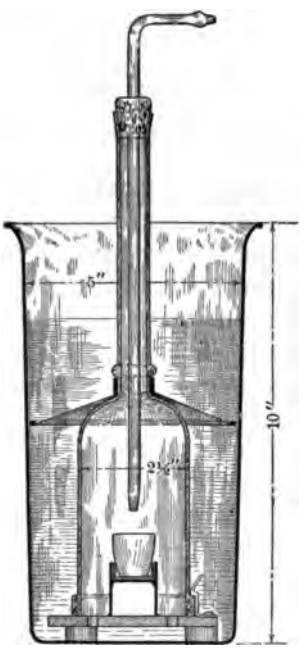


Fig. 1.

in diameter and 11 inches high, which can be obtained of most dealers in chemical apparatus. The combustion chamber is of special form, and consists of a glass bell having a notched rib around the lower edge, and a bead just above the top, with a tube projecting a considerable distance above the upper end. These have thus far been made by J. W. Staniford, 36 Hanover

Street, Boston, and they are inexpensive. The bell is 2½ inches inside diameter, 5½ inches high, and the tube above is ⅝ inches inside diameter, and extends beyond the bell a distance of 9 inches. The base consists of a circular plate of brass, 4 inches in diameter, with three clips fastened on the upper side for holding down the combustion chamber. The base is perforated, and the under side has three pieces of cork attached, which serve as feet. To the centre of the upper side of the plate is attached a cup for holding the platinum crucible in which the coal is burned. To the upper end of the bell, beneath the bead, a hood is attached, made of wire gauze, which serves to intercept the rising bubbles of gas and retard their escape from the water. The top of the tube is fitted with a cork, and through this is inserted a small glass tube which carries the oxygen to the lower part of the combustion chamber. This tube is movable up and down, and to some extent sideways, so as to direct the current of oxygen to any part of the crucible, and adjust it to a proper distance from the burning coal.

There is no patent on the instrument, and, with the above description, any one interested can, with a little trouble, secure an outfit on this plan. In addition to the apparatus here shown there is required a tank of oxygen, such as the calcium light companies furnish, scales for weighing water, and delicate balances for weighing coal, besides a delicate thermometer for taking the temperature of the water, and another for showing the temperature of the atmosphere. The former should be graduated to tenths of a degree Fahr.

In the writer's work with the instrument the quantity of coal used for a test is one gram, and of water 2,000 grams. In working out the heat units, allowance is made for the specific heat of the calorimeter, either by calculation or by experiment. Radiation is allowed for by commencing the test with a temperature as many degrees below the atmosphere as the temperature rises above the atmosphere at the end of the test. When very smoky coals are used, the sample is mixed with a small proportion of anthracite of known calorific value ; and when anthracite coal is used, a small percentage of bituminous coal is likewise mixed with it.

Samples of two bituminous coals submitted by Mr. Kent of the Committee, one of which was a highly volatile coal, were tested in this instrument, and a sample of the same submitted

to Mr. Henry J. Williams of Boston for analysis. The analyses gave the following results based on dry coal:

	No. 1.	No. 2.
Carbon	71.84 per cent.	82.27 per cent.
Hydrogen	4.81 "	4.70 "
Nitrogen	1.58 "	1.56 "
Oxygen	13.98 "	5.84 "
Ash	6.74 "	4.93 "
Volatile sulphur	1.05 "	1.20 "
	100.00	100.00

The calorific values worked out from these analyses, and those given by the calorimeter, are presented in the following table, the formula used for obtaining the total heat of combustion from the analysis being $145 \times C + 625 \times \left(H - \frac{O}{8}\right)$.

	Number.	B. T. U. Based on Dry Coal.	B. T. U. Based on Combustible.
Calorimeter	1	12,705	13,646
Analysis	1	12,323	13,208
Calorimeter	2	14,631	15,320
Analyses	2	14,452	15,197

It will be seen that in one case the two results agree within less than one per cent., and in the other case within about three per cent.

The writer has used this instrument for over seven years, and has tested over 200 samples of coal with it. The results always seem consistent with one another, and they agree substantially with those obtained from reliable analyses in cases when these have been made. G. H. B.

APPENDIX XIV.

COMPARATIVE CALORIMETRIC TESTS OF COALS.

The writer, in his paper on "The Efficiency of a Steam Boiler," presented at the St. Louis meeting, May, 1896 (*Transactions*, vol. xvii., p. 649), expressed the opinion that the variations in results of calorimetric tests of coal "throw doubt upon all calorimetric work until a sufficient number of tests shall have been made by different experimenters and with different calorimeters upon similar samples, and until tests so made show a reasonable degree of uniformity." The results of tests

of two coals by three different calorimeters were given in the paper. Mr. Barrus has since made tests of the same coals, using his own calorimeter, and they have been analyzed by Mr. Henry J. Williams, by Mr. C. H. Benedict, and also by some senior students of an engineering college in connection with their thesis work. The results of all the calorimeter tests and of the heating value calculated from the analyses are given below. Coal No. 1 was from Jackson Co., Ohio, and No. 2 from New River, W. Va.

	Heating Value per Lb. Coal, B. T. U.		Heating Value per Lb. Combustible, B. T. U.		Ratio (2)÷(1)
	(1)	(2)	(1)	(2)	
Carpenter Calorimeter	13,170	15,200	14,620	16,210	1.109
Thompson Calorimeter (Boston)	11,913	13,066	13,302	13,799	1.037
Thompson Calorimeter (St. Louis)	11,894	13,527	.....	.....	.....
Barrus Calorimeter	12,705	14,631	13,646	15,320	1.123
Analysis, Williams	12,328	14,452	13,208	15,197	1.150
Analysis, Students	10,786	14,016	12,145	14,885	1.226
Analysis, Benedict	.....	15,215	.....	15,967	.....

The results of Mr. Barrus's calorimetric test and of Mr. Williams's analyses show a fairly satisfactory agreement, but they are so much below the results of the Carpenter calorimeter, and so much above the results of the Thompson calorimeter, that the true heating value of these coals is still a matter of doubt. The results of the analysis of coal No. 1 by the students is so far below the results of the other tests of the same coal that it is of interest only in showing what great errors in analyses are possible. The ratio of the heating values of the combustible of coals No. 1 and 2 show that the relative values as well as the absolute values obtained by different calorimeters are apt to vary widely.

Mr. Benedict's analysis is given by Professor Carpenter, as follows, on dry coal: C, 85.07; H, 5.01; N, 0.82; O, 3.79; Ash, 4.71; S, 0.30; calculated heat value, 15,215 British thermal units. The samples furnished to all the experimenters were identical. The coal was crushed in a coffee mill, thoroughly mixed, and several small bottles were filled with samples of the crushed coal at the same time.

More recently the writer has obtained comparative figures by three different calorimeters and by analysis of two samples of Mt. Olive (Ill.) coal, as follows:

	Heating Value per Lb. Combustible, B. T. U.		Ratio (2)÷(1)
	(1)	(2)	
Prof. R. C. Carpenter, Carpenter Calorimeter	13,700	13,800	1.007
Prof N. W. Lord, Mahler Calorimeter	13,870	13,968	1.007
Prof. W. B. Potter, Thompson Calorimeter	13,687	13,787	1.007
Analysis by Ricketts & Banks	14,020	13,955	0.996
Average	13,819	13,878	1.004

All of these results show a remarkably close agreement. The greatest variation, that between the result by the Thompson calorimeter and by analysis, is only 2.4 per cent. These figures would indicate that the Thompson calorimeter is fairly reliable, but a very different conclusion must be drawn from the results of the tests by two Thompson calorimeters of the Jackson and the New River coals, which are far below the results obtained by the Carpenter and the Barrus calorimeters.

The conclusion to be drawn from the two series of tests tabulated above is that closely concordant results may be obtained from different calorimeters when properly handled by expert chemists, and that these results will agree with the results calculated from accurate analyses; but that occasionally very erroneous results may be obtained, and that a single calorimetric test unchecked by comparison with a test by another calorimeter is to be regarded with suspicion, especially when the test is made with a Thompson calorimeter, when the reported heating value per pound of combustible is low compared with results of other tests of coal from the same region, and when the boiler efficiency calculated from such calorimetric test is high.

W. K.

Appendix XV.

Determination of the Moisture in the Steam.

The throttling steam calorimeter, first described by Professor Peabody in the *Transactions*, vol. x., page 327, and its modifications by Mr. Barrus, vol. xi., page 790; vol. xvii., page 617; and by Professor Carpenter, vol. xii., page 840; also the separating calorimeter designed by Professor Carpenter, vol. xvii.,

page 608, which instruments are used to determine the moisture existing in a small sample of steam taken from the steam pipe, give results, when properly handled, which may be accepted as accurate within 0.5 per cent. (this percentage being computed on the total quantity of the steam) for the sample taken. The possible error of 0.5 per cent. is the aggregate of the probable error of careful observation, and of the errors due to inaccuracy of the pressure gauges and thermometers, to radiation, and, in the case of the throttling calorimeter, to the possible inaccuracy of the figure 0.48 for the specific heat of superheated steam, which is used in computing the results. It is, however, by no means certain that the sample represents the average quality of the steam in the pipe from which the sample is taken. The practical impossibility of obtaining an accurate sample, especially when the percentage of moisture exceeds two or three per cent., is shown in the two papers by Professor Jacobus in *Transactions*, vol. xvi., pages 448, 1017.

In trials of the ordinary forms of horizontal shell and of water-tube boilers, in which there is a large disengaging surface, when the water level is carried at least 10 inches below the level of the steam outlet, and when the water is not of a character to cause foaming, and when in the case of water-tube boilers the steam outlet is placed in the rear of the middle of the length of the water drum, the maximum quantity of moisture in the steam rarely, if ever, exceeds two per cent.; and in such cases a sample taken with the precautions specified in Article XIV. of the Code may be considered to be an accurate average sample of the steam furnished by the boiler, and its percentage of moisture as determined by the throttling or separating calorimeter may be considered as accurate within one-half of one per cent. For scientific research and in all cases in which there is reason to suspect that the moisture may exceed two per cent., a steam separator should be placed in the steam pipe, as near to the steam outlet of the boiler as convenient, well covered with felting, all the steam made by the boiler passing through it, and all the moisture caught by it carefully weighed after being cooled. A convenient method of obtaining the weight of the drip from the separator is to discharge it through a trap into a barrel of cold water standing on a platform scale. A throttling or a separating calorimeter should be placed in the steam pipe, just beyond the steam separator, for the purpose of determining,

by the sampling method, the small percentage of moisture which may still be in the steam after passing through the separator.

The formula for calculating the percentage of moisture when the throttling calorimeter is used is the following:

$$w = 100 \times \frac{H - h - k(T - t)}{L},$$

in which w = percentage of moisture in the steam, H = total heat, and L = latent heat per pound of steam at the pressure in the steam pipe, h = total heat per pound of steam at the pressure in the discharge side of the calorimeter, k = specific heat of superheated steam, T = temperature of the throttled and superheated steam in the calorimeter, and t = temperature due to the pressure in the discharge side of the calorimeter, = 212° Fahr. at atmospheric pressure. Taking $k = 0.48$ and $t = 212$, the formula reduces to

$$w = 100 \times \frac{H - 1146.6 - 0.48\,(T - 212)}{L}$$

W. K.

Appendix XVI.

CORRECTION FOR RADIATION FROM THROTTLING CALORIMETERS.

The formulæ usually given for determining moisture in a throttling calorimeter, including that given above by Mr. Kent, make no allowance for radiation from the exterior surfaces of the instrument. It is true that this allowance is small and does not affect the results but a small fraction of 1 per cent.; but it nevertheless exists, and should properly be taken into account. In my own work I have found that the radiation reduces the temperature of the wire-drawn steam some 6 degrees, and this represents about .3 of 1 per cent. of moisture. My practice is to allow for the radiation by determining the normal for the instrument, as described in Appendix XVII.

It should be noted here that this normal can be readily determined when the calorimeter is attached to a horizontal section of the steam pipe, and the condensing surface immediately above the sampling pipe is thus reduced to a minimum.

G. H. B.

APPENDIX XVII.

COMBINED CALORIMETER AND SEPARATOR.

The form of steam calorimeter which the writer uses is termed the "1895 pattern" universal steam calorimeter, and is a modification of the one described in the *Transactions*, vol. xi., page 790. It is illustrated in the accompanying cut (Fig. 2), which is reprinted from page 618, vol. xvii., in the *Transactions*. It consists of a throttling calorimeter and separator combined, the latter being attached to the outlet where the steam of atmos-

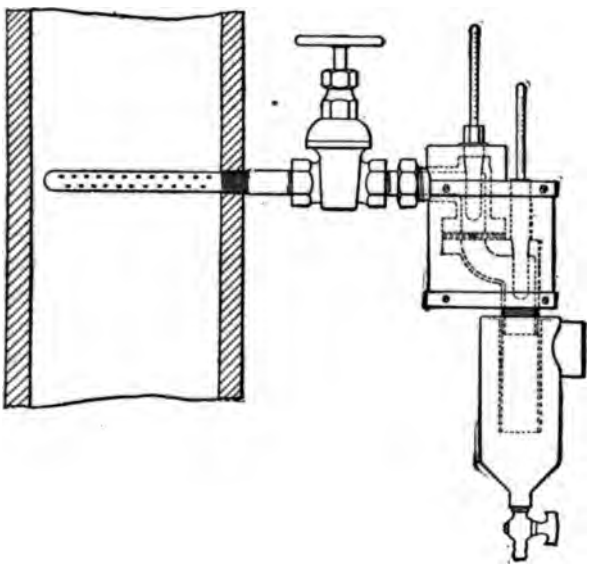


FIG. 2.

pheric pressure is escaping. If the moisture is too great to be determined by the readings of the two thermometers, the separator catches the balance, and the total quantity of moisture is made up in part of that shown by the thermometers, and in part of that collected from the separator. The percentage of moisture shown by the thermometers is obtained by referring the indication of the lower thermometer to the normal reading of that thermometer with dry steam, and dividing the fall of temperature by the constant of the instrument for one per cent. of moisture. The normal reading is determined by observing the indications when steam in the main pipe is in a quiescent state, and the constant is a quantity varying uniformly from

21 degrees at 80 pounds pressure to 20 degrees at 200 pounds pressure. The percentage of moisture, if any, discharged from the separator, is found by dividing its quantity corrected for radiation by the total quantity of steam and water passing through the instrument in the same time, as ascertained by experiment, and multiplying the result by 100.

G. H. B.

APPENDIX XVIII.

CORRECTIONS FOR QUALITY OF STEAM.

Given the percentage of moisture or number of degrees of superheating, it is desirable to develop formulæ showing what we have termed "the factor of correction for quality of steam," or the factor by which the "apparent evaporation," determined by a boiler test, is to be multiplied to obtain the "evaporation corrected for quality of steam." It has been customary to call the proportional weight of steam in a mixture of steam and water "the quality of the steam," and it is not desirable to change this designation. The same term applies when the steam is superheated by employing the "equivalent evaporation," or that obtained by adding to the actual evaporation the proportional weight of water which the thermal value of the superheating would evaporate into dry steam from and at the temperature due to the pressure. "The factor of correction for quality of steam" in a boiler test differs from the "quality" itself, from the fact that the temperature of the feed water is lower than that of the steam.

Let

Q = quality of moist steam as described above.

Q_1 = the quality of superheated steam as described above.

P = the proportion of moisture in the steam.

k = the number of degrees of superheating.

F = the factor of correction for the quality of the steam when the steam is moist.

F_1 = the factor of correction for the quality of the steam when the steam is superheated.

H = the total heat of the steam due to the steam pressure.

L = the latent heat of the steam due to the steam pressure.

T = the temperature of the steam due to the steam pressure.

T_1 = the total heat in the water at the temperature due to the steam pressure.*

J = the temperature of the feed water.

J_1 = the total heat in the feed water due to the temperature.*

Therefore, for moist steam:

(1) . . . . . $Q = 1 - P$

(2) . . . . . $P = 1 - Q$

(3) . . . . . $Q + P = 1$

See also Equation (6).

With both the condensing and throttling calorimeters the water and steam are withdrawn from the boiler at the temperature of the steam, and with a separator the water can only be accurately measured when under pressure, so that the difference between the steam and the moisture in the steam, as they leave the boiler, is simply that the former has received the latent heat due to the pressure, and the latter has not. There is, however, imparted to the water in the boiler, not only the latent heat in the portion evaporated, but the sensible heat due to raising the temperature of all the water from that of the feed water to that of the steam due to the pressure.

In Equation (3) the proportional part Q receives from the boiler both the sensible and the latent heat, or the total heat above the temperature of the feed $= Q\,(H - J_1)$ thermal units, and the part P the difference in sensible heat between the temperatures of the steam and of the feed water $= P\,(T_1 - J_1)$ thermal units. If all the water were evaporated, each pound would receive the total heat in the steam above the temperature of the feed, or $H - J_1$. "The factor of correction for the quality of the steam," when there is no superheating, is therefore

$$(4) \quad F = \frac{Q\,(H - J_1) + P\,(T_1 - J_1)}{H - J_1} = Q + P\left(\frac{T_1 - J_1}{H - J_1}\right)$$

The superheating of the steam requires 0.48 of a thermal unit for each degree the temperature of the steam is raised, so

* Most tables of the properties of steam and of water are based on the total heat of steam and water above 32 degrees Fahr. For such tables the total heat in the water at a given temperature is equal approximately to the corresponding temperature minus 32 degrees. Exact values should, however, be taken from the tables.

for k degrees of superheating there will be $0.48k$ thermal units per pound weight of steam, and the "factor of correction for the quality of the steam," with superheating is:

$$(5) \quad . \quad . \quad . \quad F_1 = \frac{H - J_1 + 0.48k}{H - J_1} = 1 + \frac{0.48k}{H - J_1}$$

See also Equation (7).

With the throttling calorimeter the percentage of moisture, P, or number of degrees of superheating, is determined as explained in Appendices XV. and XVI.

Since the invention of the throttling calorimeter (Appendix XVI.), the use of the original condensing, or so-called barrel, calorimeter is no longer warranted. Accurate results should, however, be obtained by condensing all the steam generated in the boiler, and this plan has been followed in certain cases. It has, therefore, been thought desirable to add other formulæ applicable to condensing calorimeters. The following additional notation is required:

W = the original weight of the water in calorimeter, or weight of circulating water for a surface condenser.

w = the weight of water added to the calorimeter by blowing steam into the water, or of "water of condensation" with a surface condenser.

t = total heat of water corresponding to initial temperature of water in calorimeter.

t_1 = total heat of water corresponding to final temperature in calorimeter.

Evidently, then:

$W(t_1 - t)$ = the total thermal units withdrawn from the boiler and imparted to the water in calorimeter.

$\frac{W}{w}(t_1 - t)$ = the thermal units per pound of water withdrawn from the boiler and imparted to the water in calorimeter, from which should be deducted $T_1 - t_1$ to obtain the number of thermal units per pound of water withdrawn from the boiler at the pressure due to the temperature, T.

Since only the latent heat, L, is imparted to the portion of the water evaporated, the quality Q, or proportional quantity evaporated, may be obtained by dividing the total thermal units per pound of water abstracted at the pressure due to the tempera-

ture, T, by the latent heat, L. Hence, as given in Appendix XVII., 1885 Code, with some differences in notation:

$$(6) \quad . \quad . \quad Q \text{ and } Q_1 = \frac{1}{L}\left[\frac{W}{w}(t_1 - t) - (T_1 - t_1)\right]$$

The value Q applies when the second term is less than unity. P may be derived therefrom by substitution in Equation (2) and F from Equation (4).

Q_1 applies when the second term of the above equation is greater than unity, which shows that the steam is superheated, and, as in this case, the heating value of the superheat has already been measured by heating the water of the calorimeter; the proportional thermal value of the same, in terms of the latent heat, L, is represented directly by $Q_1 - 1$, and we have as the factor of correction for the quality of the steam, with superheating:

$$(7) \quad . \quad F_1 = \frac{H - J_1 + L(Q_1 - 1)}{H - J_1} = 1 + \frac{L(Q_1 - 1)}{H - J_1}$$

See also Equation (5).

When the quality is greater than 1, or equals Q_1, the number of degrees of superheating is:

$$(8) \quad . \quad . \quad . \quad k = \frac{L(Q_1 - 1)}{0.48} - 2.0833L(Q_1 - 1)$$

C. E. E.

Appendix XIX.

THE QUALITY OF SUPERHEATED STEAM.

The quality of the superheated steam is determined from the number of degrees of superheating by using the following formula:

$$Q = \frac{L + 0.48(T - t)}{L},$$

in which L is the latent heat in British thermal units in one pound of steam of the observed pressure, T the observed temperature, and t the normal temperature due to the pressure. This normal temperature should be determined by obtaining a reading of the thermometer when the fires are in a dead condition and the superheat has disappeared, this temperature being observed when the pressure as shown by the gauge is the aver-

age of the readings taken during the trial. Observations being made by the same instrument, errors of gauge or thermometer are practically eliminated. G. H. B.

APPENDIX XX.

EFFICIENCY OF THE BOILER.

The efficiency of the boiler, including the grate, or the efficiency based on coal, is the quotient arising from dividing the heat absorbed by the boiler by the heating value of the total amount of coal supplied to the boiler, including the coal which falls through the grate. It may be conveniently calculated by multiplying the number of pounds of water evaporated from and at 212 degrees Fahr. into dry steam per pound of dry coal by 965.7, and dividing the product by the heating value in British thermal units of one pound of dry coal.

The efficiency of the boiler, not including the grate, or the efficiency based on combustible, is the quotient arising from dividing the heat absorbed by the boiler by the heating value of the combustible burned. It may be calculated by multiplying the number of pounds of water evaporated from and at 212 degrees Fahr. into dry steam per pound of combustible by 965.7, and dividing the product by the heating value in British thermal units of one pound of combustible; the term "combustible" being defined as coal dry and free from ash, or the coal supplied to the boiler less its moisture and the ash and unburned coal which falls through the grate or is otherwise withdrawn from the furnace.

The efficiency of the boiler, not including the grate (or the efficiency based upon combustible) is a more accurate measure of comparison of different boilers than the efficiency including the grate (or the efficiency based upon coal), for the latter is subject to a number of variable conditions, such as size and character of the coal, air-spaces between the grate bars, skill of the fireman in saving coal from falling through the grate, etc. It is, moreover, subject to errors of sampling the coal for drying and for analysis, which affect the result to a greater degree than they do the efficiency based upon combustible, for the reason that the heating value of per pound of combustible of any sample selected from a given lot, such as a car-load, of coal is practically a constant quantity and is independent of the

percentage of moisture and ash in the sample; while the sample itself, upon the heating value of which the efficiency based on coal is calculated, may differ in its percentage of moisture and ash from the average coal used in the boiler test.

When the object of a boiler test is to determine its efficiency as an absorber of heat, or to compare it with other boilers, the efficiency based on combustible is the one which should be used; but when the object of the test is to determine the efficiency of the combination of the boiler, the furnace, and the grate, the efficiency based on coal must necessarily be used.

It has been proposed that in reporting the efficiency of a boiler when the fuel used contains hydrogen, the efficiency should be considered to be the sum of the percentage of the heating value of the fuel which is utilized by the boiler in making steam and of the percentage of that heating value which is lost in the shape of latent heat in the moisture in the chimney gases, which moisture is formed by the burning of the hydrogen. This latent heat may amount to over three per cent. of the total heating value of the fuel. The reason assigned for this proposal is that, since it is impossible for this heat to be utilized by the boiler because the gases are discharged at a temperature above 212 degrees Fahr., it should not be charged against the boiler. The writer does not consider it advisable that this method of reporting the efficiency should be adopted (1) because it is opposed to the generally accepted definition of efficiency, which is the useful work received from an apparatus divided by the work (or heat value of the fuel) put into it; (2) because in order to calculate it, it is necessary to know both the percentage of hydrogen in the coal and whether or not all of this hydrogen has been burned to H_2O, the first requiring an analysis of the coal, which is not always obtainable, and the second an analysis of the gases for hydrogen, which cannot be obtained with any approximation to accuracy with our present methods of sampling and analyzing gases; and (3) because it is opposed to the almost universal custom in reporting boiler tests. It is true that the latent heat of the H_2O in the chimney gases cannot be utilized (unless an economizer which discharges its gases below 212 degrees is used), and it is not the fault of the boiler that it cannot be utilized. It may be considered the misfortune of the boiler, when tested with hydrogenous coal, similar to the misfortune under which an engine labors when it

is tested while supplied with a condenser which gives a vacuum of less than 30 inches of mercury. The engine might give a higher efficiency with a vacuum of 30 inches than it would with one of 27 or 28 inches; but it is not customary to credit the engine with the efficiency which it loses on account of the imperfect vacuum.

Since it is well understood that a boiler cannot show quite as high an efficiency (as commonly defined) when using bituminous coal high in hydrogen as when using anthracite nearly free from hydrogen, no harm is done, and much confusion is avoided, by reporting the efficiency as the percentage of the heating value of the coal which is actually utilized in making steam. The fact that bituminous coal is used is always stated in the report of a test made with that coal. If desired, a statement may also be made in the "heat balance" of the approximate or estimated percentage of heat which is lost in the latent heat of the moisture in the chimney gases, together with the loss due to moisture in the coal.

W. K.

Appendix XXI.

DISTRIBUTION OF THE HEATING VALUE OF THE FUEL.

In the operation of a steam boiler the following distribution of the total heating value of the fuel takes place:

1. Loss of coal or coke through the grate.

2. Unburned coal or coke carried in the shape of dust or sparks beyond the bridge wall.

3. Heating to 212 degrees the moisture in the coal, evaporating it at that temperature, and evaporating the steam made from it to the temperature of the flue gases = weight of the moisture in pounds $\times$ [(212 degrees $- t$) + 966 + 0.48 ($T - 212$)], in which T is the temperature (Fahr.) of the flue gases and t the temperature of the external air.

4. Loss of heat due to steam which is formed by burning the hydrogen contained in the coal, and which passes into the chimney as superheated steam = 9 times the weight of the hydrogen $\times$ [(212 $- t$) + 966 + 0.48 ($T - 212$)].

5. Superheating the moisture in the air supplied to the furnace to the temperature of the flue gases = weight of the moisture $\times$ 0.48 ($T - t$).

6. Heating of the gaseous products of combustion (not including steam) to the temperature of the flue = their weight × 0.24 $(T - t)$.

7. Loss due to imperfect burning of the carbon of the coal and to non-burning of the volatile gases.

8. Radiation from the boiler and furnace.

9. Heat absorbed by the boiler, or useful work.

Item 1 depends upon the size of the spaces between the grate bars; upon the kind of grate, as a plain, shaking, or travelling grate; upon the size of the coal; upon the character of the coal, as it requires to be more or less distributed on the grate in order to get a sufficient supply of air through it; upon the rate of driving of the furnace, rapid driving with some coals requiring more frequent shaking or cleaning of the grate than slow driving; and upon the skill of the fireman.

Item 2 depends upon the nature and fineness of the coal and upon the force of the draft. It is usually so small as to be inappreciable in its effect upon the results of the trial of a stationary boiler driven with natural draft, but in locomotives, with rapid rates of combustion, it often becomes quite important.

Item 3 depends upon the amount of moisture in the coal.

Item 4 depends upon the amount of hydrogen in the coal.

Item 5 depends upon the amount of moisture in the air. The moisture in the air may be obtained from its temperature and relative humidity, as determined by a wet-and-dry-bulb thermometer, by reference to hygrometric tables. The loss of heat due to the moisture in the air will rarely exceed 0.25 per cent. of the heating value of the fuel, and it may usually, therefore, be neglected.

Item 6 depends chiefly upon the type and proportions of the boiler, and upon the rate at which it is driven. This item is usually the largest of all the heat losses.

Items 3, 4, 5, and 6 depend also on the temperature of the flue gases.

Item 7 depends upon the character of the coal and of the furnace, and upon the skill of the fireman. This loss may be very large, 20 per cent. or more of the heating value of the coal, when highly bituminous coals are used in a furnace not adapted to them.

Item 8 depends chiefly upon the type, size, and setting of the boiler, and, when expressed as a percentage of the total heat of the fuel, upon the rate at which it is driven.

Item 9 is the heat absorbed by the boiler, or the useful work. It is also the difference between the total heating value of the coal and the sum of the losses of items 1 to 8 inclusive.

W. K.

Appendix XXII.

OBSERVATION BLANKS.

The observations taken during the test should be recorded on a series of blanks prepared in advance, so as to be adapted for the purpose of the trial. The number of sheets and the number of items on each may be varied to suit the number of observers and the work designated for each. It will be found convenient and desirable to have the blanks for the coal and water observations independent of those for general observations, and in general independent of each other. In all cases the first column of the coal record and of the water record should be devoted to the time; stating, for instance, when a particular barrow of coal is dumped or a particular tank of water let down. Error is best avoided by having separate columns for gross weights, tare and net weights, even though the tare be constant. The feed-water record should contain a column for temperature in case the same is taken in the tank, and also a column for height of water in glass gauge on boiler, which is to be noted when tank is emptied if the feed pump or injector is directly connected thereto.

C. E. E.

Appendix XXIII.

HORSE-POWER.

The writer's preference for rating boilers in horse-power is:

Capacity to evaporate into dry steam, *i.e.*, not containing over three per cent. of entrained water, and the water actually entrained allowed for and deducted:

1. 34½ pounds of water from and at 212 degrees, equal to

2. 30 pounds of water of $t = 100$ degrees under $p = 70$ pounds per square inch above one atmosphere; with easy firing, moderate draft, and ordinary fuel, implying good economy, and capability of fifty per cent. increase to meet emergencies.

As to the last condition, "capability of fifty per cent. increase to meet emergencies"—

It must be obvious that a boiler which, under most favorable conditions of fuel, draft, firing, and everything else, is just capable of evaporating into dry steam 3,450 pounds of water from 212 degrees into the atmosphere, with open safety valve—or, what comes to the same thing, 3,000 pounds from $t = 100$ degrees to $p = 70$ + atmosphere—could not be called a 100 horse-power boiler with any propriety. Good ordinary practical conditions should do that, with satisfactory economy; and then fifty per cent. more should be obtainable to meet a sudden call or to supply a brief deficiency. J. C. H.

Appendix XXIV.

STEAM UNITS.

All measurements of the quantity of heat are based on the *thermal unit*, which, for British measures, equals the quantity of heat required to raise the temperature of one pound of pure water at or near its freezing-point one degree Fahr.*

The unit commonly used to express the evaporative power of the fuel is the quantity of heat required to evaporate one pound of water at a temperature of 212 degrees under the ordinary pressure of the atmosphere corresponding to that temperature. This was called by Rankine a "peculiar thermal unit," and its value given at 966.1 British thermal units, but has since been called the "*unit of evaporation*," which term is adopted in the foregoing general report of the committee. Its value, however, in the prominent American tables is given at 965.7 thermal units.

The *mechanical equivalent* of a thermal unit equals very nearly 778 foot-pounds of work, but the power that can be utilized practically per unit of heat depends on so many conditions that a universal standard of work or power (the rate of work) based on heat units is impossible. Compound engines operated with high steam slightly superheated require a little over 14 pounds of feed-water evaporated per hour, while there are still in use poor engines, ill-proportioned steam pumps, and the like that require over 60 pounds, or say one cubic foot, of water per hour, which was considered as about equivalent to a horse-power of steam in the days of Watt. It has of late years, however, been well ac-

* Compare "Rankine on Steam Engine," Art. 208; "Porter on the Richards Indicator," page 43.

cepted that 30 pounds of feed-water per hour is a fair standard of horse-power for average good high-pressure engines, such as are used for manufacturing purposes. Bearing in mind that this quantity of steam must be furnished by the boiler under actual conditions, the writer, in preparing the report of the Committee of the Judges of Group XX. appointed to test the boilers at the Centennial Exhibition, suggested to his associates, Messrs. Charles T. Porter and Joseph Belknap, that the value of the "commercial horse-power of a boiler be fixed at 30 pounds of water evaporated at 70 pounds gauge-pressure from a temperature of 100 degrees." * This standard, having been adopted in the foregoing report of the Committee of the American Society of Mechanical Engineers, may be considered as established both by precedent and authority. It is fixed as equal to 34½ units of evaporation per hour, and is, for all practical purposes, equal to 33,333 thermal units per hour, making it convenient to obtain the horse-power by multiplying the total number of thermal units derived from the fuel per hour by 0.00003. It is of interest also to note that a cubic foot of steam at 70 pounds gauge-pressure weighs ⅛ of a pound avoirdupois, so that a commercial horse-power on the above basis is also represented by 150 cubic feet of steam per hour at 70 pounds pressure.†

In preparing the general report of the judges of Group XX., Centennial Exposition, it was observed that if a boiler supplying any kind of pumping machinery be proportioned to utilize 10,000 heat units per pound of coal consumed (corresponding to an evaporation of about 9 pounds of water at 70 pounds gauge-pressure from a temperature of 100 degrees), the number of foot-pounds of work obtained in the engine for each thermal unit would also represent the duty in millions of foot-pounds per 100 pounds of coal. ‡ From this it will be seen that the commercial

---

* See report of committee at page 131 of the "Report of the Judges of Group XX." International Exh., 1876. J. B. Lippincott & Co., Philadelphia.

† In administering the steam supply of the New York Steam Company, the writer provided for selling steam at a fixed rate per thousand "*kals*," explaining that a "*kal*" meant a pound of water evaporated into steam. This term has been in use in that business since February, 1883, and has proved so convenient that the writer has suggested that it can possibly be utilized to express the unit of the commercial horse-power above referred to. On this basis a boiler horse-power would equal simply 30 "kals" per hour. See "Estimates for Steam Users," Vol. V., *Transactions* Am. Soc. Mech. Engineers, page 284.

‡ See "Report of Judges of Group XX.," Cent. Exh., pp. 21 and 115.

horse-power above referred to corresponds to a duty of 59.4 millions of pounds lifted one foot high with 100 pounds of coal, which is about the average duty of the simpler class of pumping engines, but not of first-class engines. Evidently, for the better class of steam machinery of all kinds, the steam-producing capacity of the boiler must be made to conform to the actual amount of steam to be used by the engines. Any standard of the horse-power of a boiler necessarily relates simply to its steam-producing capacity, referred to the arbitrary standard of a horse-power above mentioned. C. E. E.

APPENDIX XXV.

DISCREPANCY BETWEEN COMMERCIAL AND EXPERIMENTAL RESULTS.

The final result sought by manufacturers, in initiating tests of steam or other machinery in actual use, is the value of the work done measured in dollars and cents. In some cases the broad question is raised as to the saving that may be accomplished by installing improved boilers, engines, or other machinery; but more generally it is desired to ascertain what can be done to produce saving with the apparatus already in place under the actual conditions that prevail at the particular location. In both these cases it is necessary to ascertain the average cost of the work done commercially previous to the test. Frequently, in fact generally, this important fact will not be ascertained by an elaborate trial, for the reason that everything will be put in order for the test, and all details of the trial be conducted so carefully that the losses due to average carelessness or want of skill in the past will be eliminated, the engineer making the test will not receive proper credit, and the owners on seeing the report may conclude that they are already doing very well, and perhaps continue old methods with fancied security. If the cost of the output of the factory for a given time were ascertained in terms of the coal burned during the same time, and compared with the corresponding cost for the time of the trial, the latter would frequently be found to be one-eighth to one-third less than the former, and it might not be possible to tell what had caused the difference; for instance, whether it was due to putting in order the machinery prior to the tests, to greater care exercised by the fireman under the spur of careful watching, or whether, as is usually claimed, the

coal was different, etc., etc. The losses are generally due in the main to the carelessness of the firemen. It follows, therefore, that the cost of the power under average conditions must be obtained in some quiet way preliminarily. Frequently the comparison of the output of the factory with the coal burned will not be sufficiently accurate, and it will be necessary to devise some corresponding check which will not interfere with the regular routine of the establishment. The work of the boilers may be checked by arranging a meter so as to continuously measure the feed water; and its record, compared with the total weight of coal *purchased*, will frequently give the check desired. Such a check becomes more difficult when it is desirable to ascertain the performances of particular boilers, and the coal supply is common to all boilers; but by assigning particular weighed carloads of coal to the particular boilers, without any intimation to the firemen that they are being watched, it may be possible to ascertain the average performance of the boilers used for the particular purpose. Preliminary experiments of this kind conducted without notice to employees, and continued through a long period, will furnish a basis for comparison with elaborate tests, and it will then be possible to point out clearly where the several losses have taken place, and the testing engineer will get the credit for the saving shown.

C. E. E.

APPENDIX XXVI.

RECORDING STEAM GAUGE.

A good recording steam gauge, Edson's or other, carefully adjusted, should be used and accurately compared with the steam gauge at stated intervals. Such an automatic record, nicely integrated, is a good check on the record of the steam gauges.

J. C. H.

APPENDIX XXVII.

PYROMETER.

So far as known to me the only way to measure temperatures between 600 or 700 degrees Fahr., or above the range of the air thermometer, and 2,500 or 2,700 degrees Fahr., or up to the melting point of commercial platinum, is by the platinum water-pyrometer.

One form of this pyrometer is described in the journal of the Franklin Institute, Vol. 84, pp. 169 and 252, September and October, 1882. J. C. H.

PYROMETER.

The temperature of the escaping gases should be ascertained, not by pyrometers, but by means of certified mercury thermometers introduced at a number of different points in the same plane transverse to the flue. The velocity of the current should be ascertained at each of these points. The distance of the transverse plane of observation from the boiler should be noted.

C. T. P.

Appendix XXVIII.

DRAFT GAUGE.

Some instruments for indicating the force of chimney draft:

a. A bent glass tube filled with water.

b. A bent tube with two fluids.

c. An encased aneroid.

d. A differential pressure gauge.

The encased aneroid, having inches of mercury indicated by spaces of about 2 inches, divided to $\frac{1}{100}$, answers well. The case is airtight, and by means of a three-way cock the interior of the case may be put alternately in communication with the external air and with any flue into which a suitable pipe is inserted.

The differential pressure gauge was devised and put to use at the Massachusetts Institute of Technology, and similar instruments should be manufactured for sale. I will not attempt to describe it further than to say that a column of water in a glass tube, acting on a small diaphragm, balances the weight of the movable parts when a large diaphragm is in equilibrium of pressure. Now if this large diaphragm have chimney pressure on the inner side and atmospheric pressure on the outside, the difference of pressure will be shown by a rise of water in the glass tube to a height proportioned to the ratio of the areas of the small and large diaphragms.

Draft should be measured in different parts of the flue, in order to detect infiltration of air through cracks in the brickwork and through the brickwork itself. J. C. H.

APPENDIX XXIX.

DRAFT GAUGE.

The ordinary form of draft gauge, consisting of the U tube, containing water, lacks sensitiveness when used for measuring small quantities of draft. An instrument (Fig. 3) which the writer has used satisfactorily for a number of years multiplies the ordinary indications as many times as desired. It consists

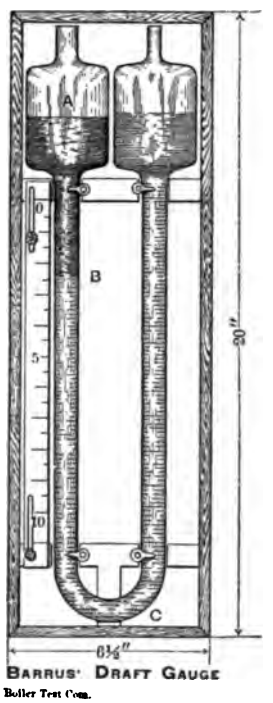


FIG. 3.

of a U tube made of ½-inch glass, surmounted by two larger tubes, or chambers, having a diameter of 2½ inches, as shown in the cut. Two different liquids which will not mix, and which are of different color, are used, one occupying the portion *A B*, and the other the portion *B C D*. The movement of the line of demarcation is proportional to the difference in the areas of the chambers and of the U tube below. The liquids generally employed are alcohol colored red and a certain grade of lubricating oil. A multiplication varying from eight to ten

times is obtained under these circumstances; in other words, with ¼-inch draft the movement of the line of demarcation is some two inches.

The instrument is calibrated by referring it to the ordinary U-tube gauge.

G. H. B.

Appendix XXX.

DRAFT GAUGE.

The accompanying sketch (Fig. 4) represents a very sensitive and accurate draft gauge recently constructed by the writer. A light cylindrical tin can *A*, 5 inches diameter and 6 inches high,

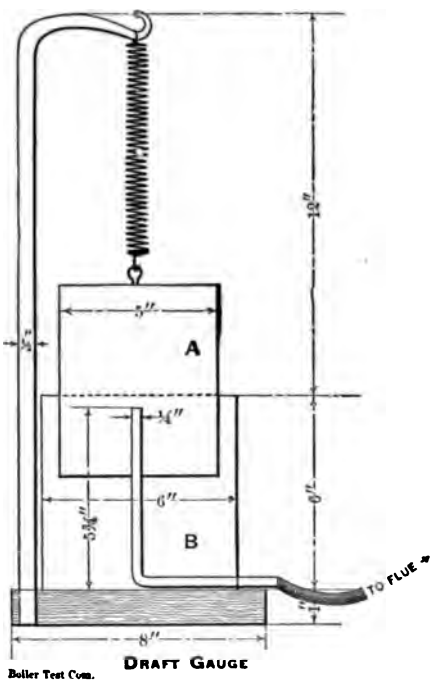


FIG. 4.

is inverted and suspended inside of a can *B*, 6 inches diameter, 6 inches high, by means of a long helical spring. Inside of the larger can a ¼-inch tube is placed, with one end just below the level of the upper edge, while the other end passes through a

hole cut in the side of the can, close to the bottom, solder being run around the tube so as to close the hole and make the can water-tight. The can is filled with water to within about half an inch of the top, and the inner can is suspended by the spring so that its lower edge dips into the water, the height of the support of the spring being adjusted accordingly.

The small tube being open at both ends, the air enclosed in the can A is at atmospheric pressure, and the spring is extended by the weight of the can. The end of the tube which projects from the bottom of the can being now connected by means of a rubber tube with a tube leading into the flue, or other chamber, whose draft or suction is to be measured, air is drawn out of the can A until the pressure of the remaining air is the same as that of the flue. The external atmosphere pressing on the top of the can A causes it to sink deeper in the water, extending the spring until its increased tension just balances the difference of the opposing vertical pressures of the air inside and outside of the can. The product of this difference in pressure, expressed as a decimal fraction of a pound per square inch, multiplied by the internal area of the can in square inches, equals the tension of the spring (above that due to the weight of the can) in pounds or fraction of a pound. The extension of a helical spring being proportional to the force applied, the distance travelled downward by the can A measures the force of suction; that is, the draft. The movement of the can may conveniently be measured by having a celluloid scale graduated to 50ths of an inch fastened to the side of the can A, and a fine pointer fixed to the upper edge of the can B, almost touching the scale.

To reduce the readings of the scale to their equivalents in inches of water column, as read on the ordinary U-tube gauge, we have the following formulæ:

Let

P = force in pounds required to stretch the spring 1 inch.

E = elongation of the spring in inches.

A = area of the inner can in square inches.

d = difference in pressure or force of the draft in pounds per square inch.

D = difference in pressure in inches of water = $27.71d$.

$$EP = Ad = \frac{AD}{27.71} = 0.0361AD$$

$$D = \frac{27.71EP}{A}$$

$$E = \frac{0.0361AD}{P}$$

The last equation shows that for a constant force of draft the elongation of the spring or the movement of the can may be increased by increasing the area of the can or by decreasing the strength of the spring. The strength of the spring may be increased, that is, its sensitiveness may be decreased, by increasing either its length or the diameter of the helix, or by decreasing the diameter of the wire of which it is made. We thus have at command the means of making the apparatus of any desired degree of sensitiveness.

Applying the above formulæ, let it be required to determine the movement of the can corresponding to a draft of 1 inch of water column, the can A having a diameter of 5 inches = 19.63 inches area, and the spring of such a strength that 0.1 pound elongates it 1 inch. Here $P = 0.1$; $A = 19.63$; $D = 1$.

$$E = \frac{0.0361 \times 19.63}{0.1} = 7.09 \text{ inches.}$$

That is, the instrument multiplies the readings of the U tube 7.09 times. The precision of the instrument is, however, far greater than this figure would indicate; for in the U tube it is exceedingly difficult to read with precision the difference in height of the two menisci, while with this apparatus readings in the scale may easily be made to $\frac{1}{50}$ inch, which, with the multiplication of 7, is equivalent to $\frac{1}{350}$ of an inch of water column. The instrument may also be calibrated by directly comparing its readings with those of an ordinary U-tube gauge. W. K.

Appendix XXXI.

SAMPLING FLUE GASES.

Very great diversities in the composition of flue gases often exist in the same flue at the same time. To obtain a fair sample, it has been found sufficient to have one orifice to draw off gases

through for each 25 square inches of cross section of flue. The pipes must be of equal diameter and of equal length. One-quarter-inch gas pipes, all alike at the ends, and of equal lengths, answer well. Similar steel tubes will be still better.* These should be secured in a box or block of galvanized sheet iron, equal in thickness to one course of brick, in such a manner that the open ends may be evenly distributed over the area of the flue *A* (Fig. 57*a*), and their other open ends enclosed in the receiver *B*. If the flue gases be drawn off from the receiver *B* by four tubes, *CC*, into a mixing box, *D*, beneath, about 3-inch cube, a

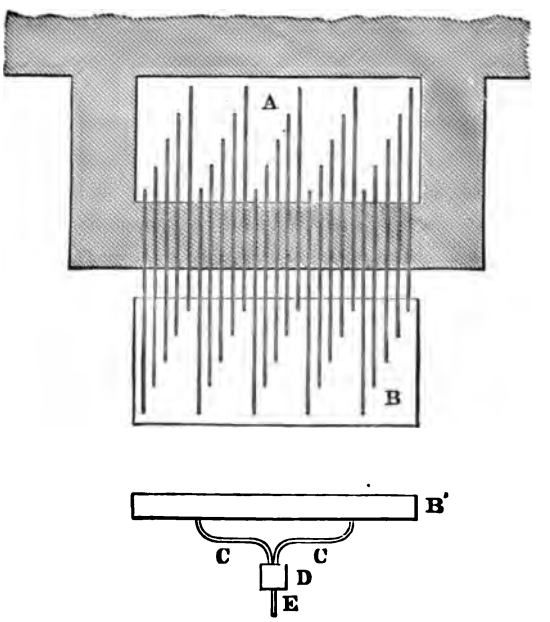


FIG. 5.

good mixture can be obtained. Two such "samplers," one above the other a foot apart, in the same flue, will furnish samples of gases which show by analysis the same composition.

J. C. H.

* Because smoother and more uniform.

Appendix XXXII.

COMPUTATION OF THE WEIGHT OF THE CHIMNEY GASES FROM THE ANALYSIS BY VOLUME OF THE DRY GAS.

Two methods of calculating from the analysis by volume of the dry chimney gases the number of pounds of dry chimney gases per pound of carbon, or the weight of air supplied per pound of carbon, have been given by different writers. These may be expressed in the shape of formulæ as follows:

$$\text{(A) Pounds dry gas per pound C} = \frac{11CO_2 + 8O + 7(CO + N)}{3(CO_2 + CO)}$$

$$\text{(B) Pounds air per pound C} = 5.8\,\frac{2(CO_2 + O) + CO}{CO_2 + CO}$$

Formula A may be derived from the method of computation given in Mr. R. S. Hale's paper on "Flue-Gas Analyses," *Transactions*, vol. xviii., p. 902, and formula B from the method given in Peabody and Miller's "Treatise on Steam Boilers." Both are based on the principle that the density, relatively to hydrogen, of an elementary gas (O and N) is proportional to its atomic weight, and that of a compound gas (CO and CO_2) to one-half its molecular weight. Both formulæ are very nearly accurate when pure carbon is the fuel burned, but formula B is inaccurate when the fuel contains hydrogen, for the reason that that portion of the oxygen of the air supply which is required to burn the hydrogen is contained in the chimney gas as H_2O, and does not appear in the analysis of the dry gas.

The following calculations of a supposed case of combustion of hydrogenous fuel illustrates the accuracy of formula A and the inaccuracy of formula B. Assume that the coal has the following analysis: C, 66.50; H, 4.55; O, 8.40; N, 1.00; water, 10.00; ash and sulphur, 9.55—total, 100. Assume also that one-tenth of the C is burned to CO, and nine-tenths to CO_2; that the air supply is 20 per cent. in excess of that required for this combustion; that the air contains one per cent. by weight of moisture; and that the S in the coal may be considered as part of the ash. We then have the following synthesis of results of the combustion of 100 pounds of coal:

	O from Air	N = O × 3.773	Total Air	CO_2	CO	HO_2
59.85 lbs. C to CO_2 × 2⅔	159.60	534.31	693.91	219.45	.....	.....
6.65 " C to CO × 1⅓	8.87	29.70	38.57	.....	15.52	.....
3.50 " H to H_2O × 8	28.00	93.74	121.74	.....	.....	31.50
	196.47	657.75	854.22	.....	.....	.....
1.05 " H to H_2O	.....	.....	.....	.....	.....	9.45
8.40 " H to H_2O						
10.00 " Water	.....	.....	.....	.....	.....	10.00
1.00 " N	.....	1.00	.....	.....	.....	.....
9.55 " Ash and S	.....	.....	.....	.....	.....	.....
100.00	.....	.....	.....	.....	.....	.....
Excess of air 20 per cent.	39.29	131.55	170.84	.....	.....	.....
	.....	.....	1,025.06	.....	.....	.....
Moisture in air 1 per cent.	.....	.....	.....	.....	.....	10.25
Total wt. of gases, 1,125.67 =	39.29	790.30	.....	219.45	15.52	61.20
Total dry gases, 1,064.56						

	O	N		CO_2	CO	
Total dry gases, by weight, %	3.69	74.24	.....	20.61	1.546	.....
Total dry gases, by volume, %	3.508	80.656	.....	14.252	1.584	.....

Total gases 1,125.76 + ash and S 9.55 = 1,135.31 total products.
Total air 1,025.06 + moisture in air 10.25 + coal 100 = 1,135.31.
Dry gas per pound coal 10.6456; per pound carbon = 10.6456 ÷ 665 = 16.008.
Dry air per pound coal 10.2506; per pound carbon = 10.2506 ÷ 665 = 15.414.

Computation of the weight of dry gas and of air per pound C—

Formula A:

$$\text{Dry gas per pound C} = \frac{14.252 \times 11 + 3.508 \times 8 + 82.240 \times 7}{3(14.252 + 1.584)} = 16.008 \text{ pounds.}$$

Formula B:

$$\text{Air per pound C} = 5.8\,\frac{2(14.252 + 3.508) + 1.584}{14.252 + 1.584} = 13.589 \text{ pounds.}$$

The error in the last result is 15.414 − 13.589 = 1.825 pounds.

Professor D. S. Jacobus gives another formula for the air per pound of carbon, in which the error of formula B is almost entirely avoided. It is

Formula C:

$$\text{Air per pound C} = \frac{7N}{3(CO_2 + CO)} \div 0.77, \text{ or } \frac{N}{0.33(CO_2 + CO)},$$

in which N, CO_2, and CO are the percentages by volume of these gases. Making the computation, from the data of the above analysis, we have:

$$\text{Air per pound C} = \frac{80.656}{0.33(14.252 + 1.584)} = 15.434 \text{ pounds,}$$

the true value being 15.414 pounds. W. K.

APPENDIX XXXIII.

THE ORSAT APPARATUS FOR ANALYZING FLUE GASES.

For the past three years the writer has made extensive use of the Orsat apparatus in his boiler testing, and has found the work not only interesting, but exceedingly instructive and valuable. Its chief value lies in the guide which it affords in determining what kind of firing is most advantageous where the fuel is bituminous coal. That the instrument is reliable and useful for the purposes noted is quickly ascertained, and without any very extended practice. When the thickening up of the fire is invariably attended with an increase in the percentage of carbonic oxide, and a reduction in the percentage of oxygen, as the writer has found, he feels at once assured that the instrument is not a plaything, or something that is influenced in unexplained ways by whim or caprice, but rather that it is an important adjunct to the engineer's outfit. In applying the results of analyses to working out the heat balance of a boiler test, the writer's results on various types of boilers, and with various fuels, have furnished a very satisfactory account of the distribution of the heat. The "unaccounted for" quantity has ranged from 2.1 per cent. up to 7 per cent. in different cases. He has never found that quantity a minus one.

As to sampling the gases, the writer has found satisfactory results from using a single tube unperforated, which extends into the flue to a central point, care being taken to so locate the inlet end that it will receive what would be considered a fair sample. In using the Orsat apparatus, it is important that the connecting tube between the flue and the instrument should be tight, and that care be taken to thoroughly exhaust the pipe of air before the sample is drawn. This, however, applies quite as much to one apparatus as to another. It is important, too, that the connections and stopcocks about the instrument itself should be tight and carefully manipulated. It is of the first importance that the absorbing liquids be in good condition. It is well for the engineer himself to make the cuprous chloride which is required for absorbing the carbonic oxide, and to frequently renew it in the apparatus.

The writer has found it desirable to locate the gas apparatus on the boiler-room floor, near by the furnaces where the fires are being handled, and carry the gases from the flue to the Orsat

by means of a lead pipe of small bore. The apparatus can then be manipulated in plain view of all the operations going on in the fire-room, and in that way he can time the drawing of samples to good advantage. By using proper judgment as to when to draw the sample, satisfactory results can be obtained from analyses covering momentary drawings. For the purposes of the boiler test and working of the heat balance, it is preferred, however, that the drawings should cover the entire period which elapses between two successive firings.

The successful manipulation of the Orsat apparatus is not a thing which requires expert chemical knowledge, for it can be properly handled by anyone, after a little practice, who is familiar with the operation of instruments of measurement.

G. H. B.

Appendix XXXIV.

SMOKE MEASUREMENTS.

In a series of competitive trials between two furnaces which the writer made in June, 1897, for the Detroit Water Works, a method of obtaining a continuous record of the quantity of smoke was introduced, which seems to him of great value in making specific what has heretofore been based upon the judgment of the person conducting the observations. The method referred to consisted simply in suspending, at a suitable point in the smoke passage between the boiler and the flue, a smooth, flat, brass plate, having its face at right angles to the direction of the current. This plate served to collect a certain portion of the soot which was carried along by the waste gases, and indirectly furnished a means of sampling the gas in respect to its smokiness. The plate was 24 inches long and $\frac{1}{8}$ of an inch wide, and it presented a surface amounting to 21 square inches. Being inserted through a hole in the top of the flue, and suspended by a wire, the hole being covered, the plate could be readily withdrawn from its place whenever desired, and the collection of soot removed by the use of a stiff brush. This was done every two hours during the progress of the trial. The quantity of soot which collected on this plate varied according to the type of the furnace and the character of the fuel, as also according to the conditions of the firing and the working conditions of the boiler. The records of the smoke-measuring device, and those of the ocular observations of the chimney, were in

accord with each other. The quantity of soot which was collected, reduced to the hourly rate, varied in these tests from nine milligrams to 184 milligrams. The method has not as yet been tried in the case of a flue carrying very dense smoke.

G. H. B.

APPENDIX XXXV.

THE RINGELMANN SMOKE CHART.

Professor Ringelmann, of Paris, has invented a system of determining the relative density or blackness of smoke, which has been communicated to the writer by Mr. Bryan Donkin, of London, and published in *Engineering News* of November 11, 1897. In making observations of the smoke proceeding from a chimney, four cards ruled like those in the cut, together with a card printed in solid black and another left entirely white, are placed in a horizontal row and hung at a point about 50 feet from the observer and as nearly as convenient in line with the chimney. At this distance the lines become invisible, and the cards appear to be of different shades of gray, ranging from very light gray to almost black. The observer glances from the smoke coming from the chimney to the cards, which are numbered from 0 to 5, determines which card most nearly corresponds with the color of the smoke, and makes a record accordingly, noting the time. Observations should be made continuously during say one minute, and the estimated average density during that minute recorded, and so on, records being made once every minute. The average of all the records made during a boiler test is taken as the average figure for the smoke density during the test, and the whole of the record is plotted on cross-section paper in order to show how the smoke varied in density from time to time. A rule by which the cards may be reproduced is given by Professor Ringelmann as follows:

Card 0. All white.

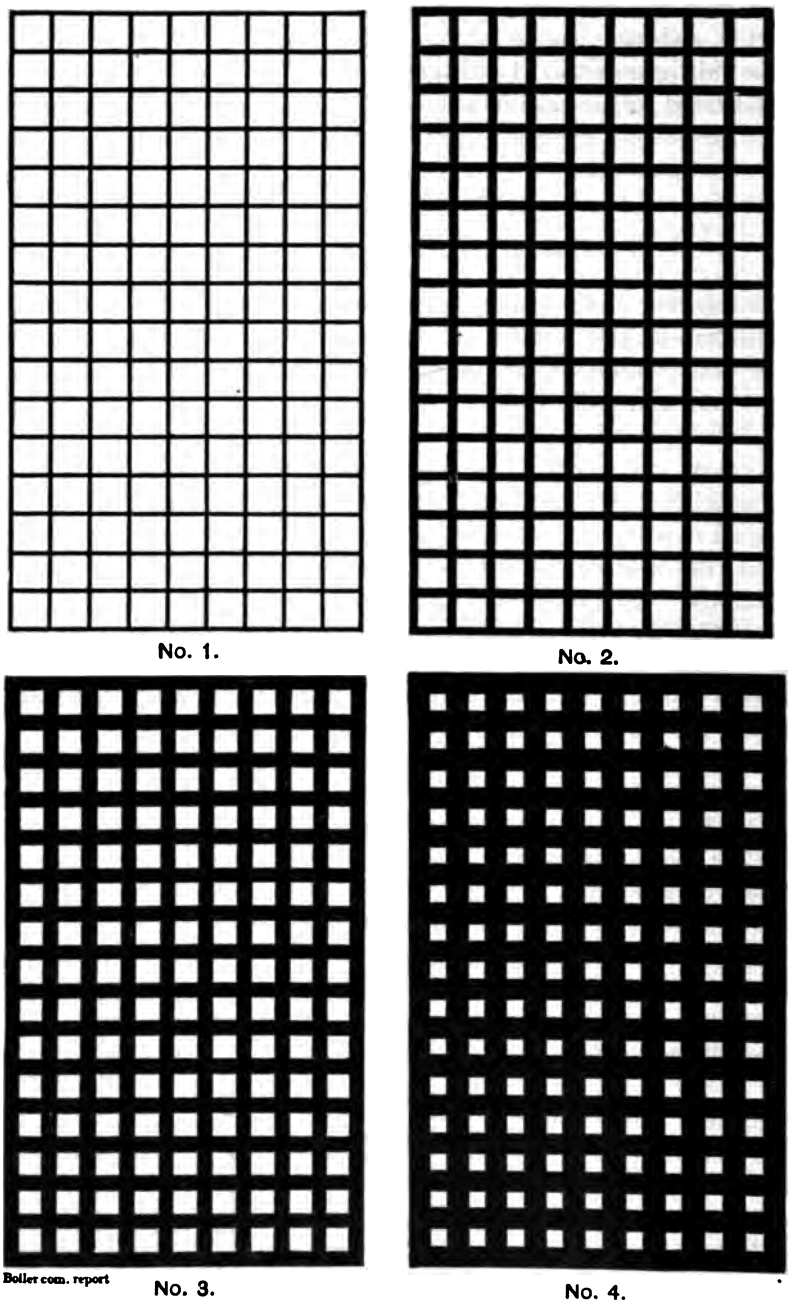
Fig. 6.—Card 1. Black lines 1 mm. thick, 10 mm. apart, leaving spaces 9 mm. square.

Fig. 6.—Card 2. Lines 2.3 mm. thick, spaces 7.7 mm. square.

Fig. 6.—Card 3. Lines 3.7 mm. thick, spaces 6.3 mm. square.

Fig. 6.—Card 4. Lines 5.5 mm. thick, spaces 4.5 mm. square.

Card 5. All black.



THE RINGELMANN SCALE FOR GRADING THE DENSITY OF SMOKE.

FIG. 6.

The cards as printed on page 98 are much smaller than those used by Professor Ringelmann, but the thickness and the spacing of the lines are the same.

W. K.

APPENDIX XXXVI.

STARTING AND STOPPING A TEST.

Of the two methods of starting and stopping a test, the so-called "standard" method and the "alternate" method, the writer prefers the latter, believing that the errors in the estimation of the quantity and condition of the small amount of coal left on the grate after cleaning are less than the errors of the "standard" method, which are due: first, to cooling of the boiler at the beginning and end of the test; second, to the imperfect combustion of the fuel at the beginning; and third, to excessive air supply through the thin fire while burning down before the end of the test.

A special caution is needed against a modification of the "alternate" method, which has been adopted by some testing engineers within the past few years. It consists in taking the starting and the stopping times each at a time subsequent to the cleaning, say after 400 pounds of coal has been fired since the cleaning. There are two sources of serious error in this method, one causing an incorrect measurement of the coal, the other an incorrect measurement of the water. Suppose 200 pounds of hot coke are left on the grate at the end of cleaning and 400 pounds of fresh coal are added by the end of, say, half an hour after cleaning. If the coal left at the end of the cleaning, and the boiler walls also, are very hot, and the coal is highly volatile and dry, and the pieces of such size as not to choke the air supply, the fire may burn so briskly that at the end of the half-hour the fuel value of the partly burned coal left out of the total 600 pounds is equivalent only to 200 pounds of coal. If, on the contrary, the hot coke on the grates at the end of the cleaning, and the boiler walls, are considerably cooled, if the fresh coal fired is moist and of small size, such as the slack of run-of-mine bituminous coal, which is often found in one portion of a pile in greater quantity than in another, the fire during the half-hour may burn so sluggishly that the coal and coke on the grate at the end of the half-hour may have a fuel value equal to 400 pounds

of coal. If, in this case, it is assumed that the quantity and condition of the coal at the end of the half-hour after cleaning are the same at the starting and stopping time, and if the fire burned briskly during the half-hour before starting and slowly during the half-hour before stopping, the boiler will be charged with more coal than was actually burned. If, on the contrary, the coal burns away more slowly during the half-hour after the cleaning before the starting time and more rapidly during the half-hour before the end of the test, the boiler is not charged with as much coal as was actually burned.

The error in water measurement is due to the fact that the condition of the fire, and especially the quantity of flaming gases arising from it, influences the height of the water level. A bright hot fire, or a fire with an abundance of burning gas proceeding from it, causes the water level to rise; while anything that cools the furnace, such as freshly fired coal, an open fire door, or a check to the draft, causes the water level to fall. A rise or a fall of several inches in a few seconds frequently occurs when bituminous coal is used. If the water level is noted at the starting of the test, when it is raised by a bright fire, and at the end of a test, when it is depressed by the stoppage of violent ebullition or of rapid circulation, due to the cooling of the fire, the boiler will be credited with more water than was really evaporated, and *vice versa.*

The only correct times to be noted as the starting and the stopping times are when the smallest amount of fuel is on the grate and when it is in the most burned-out condition; that is, just before firing fresh coal after cleaning, and when the water level is in its most quiet condition and the least raised by ebullition; that is, after the furnace door has been kept open for some time for cleaning and the furnace therefore is in its coolest state. This condition of fire and of water level can be duplicated immediately after cleaning the fire; but there is no certainty of duplication of any condition when there is a bright fire and consequent rapid steaming.

These statements are not based upon theoretical considerations, but are the results of many experiments made by the writer to determine the best starting and stopping times. In a long series of tests with bituminous coals no less than six different times were recorded as starting times and as many as stopping times, and the coal apparently used and the water

apparently evaporated recorded and calculated for each. These times were: *A*, before opening the first or right-hand door to clean the fire; *B*, after cleaning the first half of the furnace and just before firing fresh coal; *C*, after cleaning the second half of the furnace; *D*, after 200 pounds of fresh coal had been fired; *E*, after 400 pounds; *F*, after 600 pounds. By plotting the apparent water evaporation between *A* and *E*, both for starting and for stopping times, it was seen that there was nearly always an apparent negative evaporation between *B* and *D*, and sometimes between *B* and *C* and between *B* and *E*, due to the correction for height of observed water level, the level rising rapidly, being much greater than the water fed by the pump. There was often no similarity of appearance of the plotted diagrams between *A* and *F* at the beginning and at the end of the same test. The possible error of water measurement due to taking *A*, *D*, *E*, or *F* as the starting time was sometimes as much as 2,000 pounds of water, or about 3 per cent. of the whole amount evaporated in a ten-hour test. The record of water evaporated between the stopping and starting times *C* occasionally differed considerably from that taken between the *B* start and stop, due to the fact that sometimes between *B* and *C* there was a sudden lighting up of the fresh coal on the cleaned side of the furnace, while at other times the fire would not light up brightly until after the *C* point had passed. It was therefore decided that the *B* time, when the furnace was the coldest and the water level at the lowest, was the only time which could be accepted as the true starting and stopping time. W. K.

APPENDIX XXXVII.

STARTING AND STOPPING A TEST.

Between the "standard" method and the "alternate" method of starting and stopping a test I believe the standard method, if properly followed, is the more reliable of the two for determining absolutely correct and unquestionable results. One of the important matters which the standard method determines accurately is the absolute quantity of ash and refuse. In the case of the alternate method it is extremely difficult to obtain the quantity of ash in such a way as to be positively reliable, for the reason that in cleaning the fire it is hardly possible to leave the same amount of ash, clinkers, and refuse mixed with

the coal at one time as at the other. When the fire is started new with wood, and burned out at the end of the trial, as it is in pursuing the standard method of starting and stopping, there is absolutely no chance of making an error of this nature. The tendency of nearly all parties concerned in a boiler test is to have the boiler make a good showing, and it is the rule rather than the exception that the fire at the end of the test is burned lower, if anything, than it was at the beginning, so as to surely give the boiler all the advantage to which it is entitled. With this tendency the cleaning of the fire at the end of the test is apt to be less thorough than at the beginning, so that in the first place no fuel will be lost, and in the second place that the bed of coal may not be reduced in thickness any lower than is absolutely necessary. The result is that the bed of coal at the end is apt to contain more waste material, which belongs with the ashes, than it does at the beginning, and this is one of the reasons why the alternate method of starting and stopping a test is objectionable.

There appears to be confusion in the minds of some experts as to the facility with which a new fire can be started with wood. They appear to hold the belief that there is apt to be a great loss in getting a new fire started in this way, a loss which occurs not only in the matter of time, but also in the matter of combustion and heat. I have made a great many tests, using the standard method of starting and stopping, and my experience has been that, so far as facility of manipulation is concerned, it is perfectly easy and satisfactory to use the standard method. With a suitable quantity of dry pine wood, preferably in the form of edgings, or 1-inch boards which have been split into narrow pieces, it is quite feasible to draw the old fire, kindle a new one, and have the boiler under steam in practically a normal condition of running, with the coal selected (supposing this to be a good quality of bituminous or semi-bituminous coal), inside of 15 minutes' time. My opinion is that the objections which have been raised to starting with wood fires is due to the fact that suitable preparation has not been made in the matter of furnishing a proper kind of wood cut into proper shape. Certainly, it is impossible to start a satisfactory new fire if the supply of wood contains any appreciable quantity of wet material or hard wood, or wood which is in thick pieces which do not readily ignite. I have myself had difficulty in

starting a test under these circumstances, and I have no doubt that experts who have found the standard method objectionable have encountered the same obstacle, and they probably base their objections, largely at least, on these unnecessary difficulties.

G. H. B.

Appendix XXXVIII.

CHART SHOWING GRAPHICALLY THE LOG OF A TRIAL.

The well-known method of plotting observations and data on cross-section paper and making a chart applying to the test is a useful means of representing the exact uniformity of conditions existing during a trial. Such a chart is illustrated in the appended cut (Fig. 7), in which the abscissæ represent times, and the ordinates, on appropriate scales, the various observations and data. G. H. B.

Appendix XXXIX.

CONTINUOUS DETERMINATIONS OF CARBONIC ACID IN FLUE GASES.

Various forms of apparatus have been devised for showing continuously the percentage of carbonic acid in waste gases, and instruments of this kind, if reliable, serve a useful purpose in the management of the fires during the progress of a test. Among these instruments may be mentioned the "gas balance" of Alphonse Custodis, the Ardnt "econometer," and the Uehling and Steinbart "gas composimeter." G. H. B.

Appendix XL.

MEASURING RADIATION FROM CERTAIN TYPES OF BOILERS.

(Contributed by Mr. R. S. Hale, Member of the Society.)

While the heat lost by radiation is only a small amount of the total heat if the boiler is well covered, yet it is important enough to be considered, and in the case of certain internally fired boilers, such as the ordinary upright vertical, the Manning, the marine, the Thorneycroft, etc , it can be easily determined by

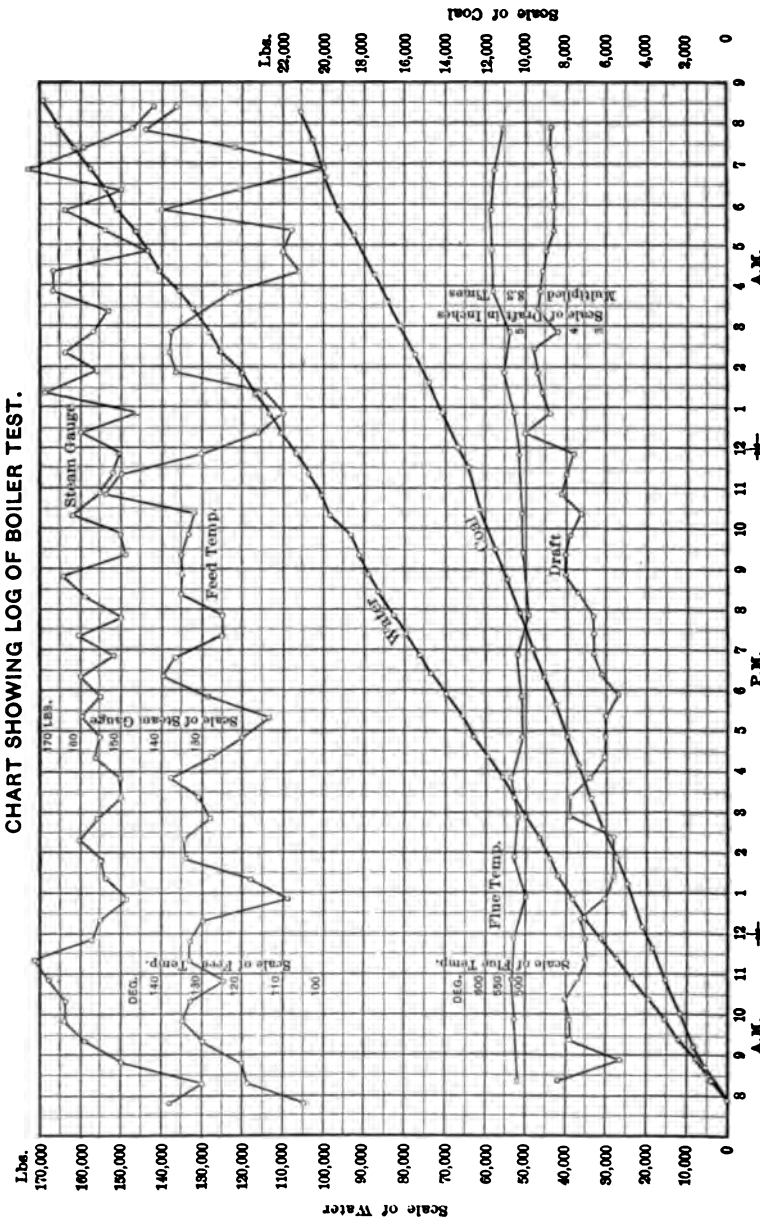


CHART SHOWING LOG OF BOILER TEST.
Scale of Water
Scale of Coal
Water
Coal
Draft
Feed Temp.
Steam Gauge
Flue Temp.
Scale of Draft in Inches Multiplied by 3.3
Scale of Steam Gauge
Scale of Feed Temp.
Scale of Flue Temp.
A.M.
P.M.
Boiler Com. Report

FIG. 7.

at least two methods. If the boiler is covered completely (or nearly so) with any boiler covering for which the rates of flow of heat can be or have been determined, then the total loss of heat is easily computed. Thus, Norton's tests (*Transactions*, vol. xix., p. 729) give the flow per square foot per hour at various differences of temperature for many frequently used coverings. Now if the temperature of the steam and of the air and the total exposed area is known, the loss from the whole boiler per hour is easily computed, and this loss divided by the total heat supplied in the same time gives the percentage loss by radiation. If the boiler is only partially covered, the loss from the covering and from the bare iron can be computed separately.

The second method of determining the radiation loss is, after drawing the fire, to shut all doors and dampers tight, and then to note the time necessary for the steam pressure to fall say ten or twenty pounds. The fall in pressure gives the data from which the fall in temperature can be computed by means of the steam tables, and the total loss of heat in thermal units is equal to the weight of iron and water multiplied by their respective specific heats and the fall of temperature. This divided by the time gives the total heat units lost by radiation per hour, and the percentage loss by radiation is found as before by dividing by the total heat supplied.

Strictly speaking, this is the radiation at the average pressure during the radiation test, but if the pressure does not fall over 20 per cent. (20 pounds in 100 or 30 pounds in 150), the result may be considered close enough to the radiation at the initial pressure, so far as this error is concerned.

It should be noted that the first method given does not apply unless the boilers are internally fired. Neither does the second method apply if there is any brick in the furnace, or setting, since the method depends on the assumption that the temperature of the water and iron corresponds to the steam pressure, which would not be true of the brick. The second method is also apt to give high results, as it is almost impossible to absolutely close the doors and dampers, and air leaking past them carries heat up the chimney, in addition to the true radiation. Nevertheless, the determination of the radiation by these methods takes but little time or trouble, and should be done whenever the type of boiler and conditions allow. Usually

both methods are available, if either is, and in such case both methods should be used and the results noted. The lower result of the two methods is the more apt to be correct, and should be taken.

It should be noted that if the temperature of the air in the boiler-room is greater than the temperature of the external air, the difference is due to radiation from the boiler, and if in making up the heat balance the temperature of the air in the boiler-room is taken as a base, the radiation necessary to heat up this air should be noted. If, however, the temperature of the external air is taken as a base in making up the heat balance, this loss cancels out, as it is returned to the boiler in the entering air. The loss by radiation as measured by either of the methods given above is, of course, in addition to the radiation that is utilized by heating the moving air before it enters the boiler.

APPENDIX XLI.

DETERMINATION OF THE MOISTURE IN STEAM FLOWING THROUGH A HORIZONTAL PIPE.

(Contributed by D. S. Jacobus, Member of the Society.)

In some cases it is impossible to place the sampling nozzle in a vertical steam pipe rising from the boiler as recommended in Article XIV. of the Code. When this is the case and it is possible to connect to a horizontal steam pipe, the arrangement of throttling calorimeters shown in Fig. 8 gives satisfactory results.

The calorimeter A is attached to the separator G, which is in turn attached to the under side of the steam pipe by the nipple D. The nipple D is made flush with the bottom of the pipe. The calorimeter B is attached to a nozzle having no side holes, which passes through the stuffing-box E. This nozzle is adjustable so that the steam can be drawn from any height in the pipe. When in its lowest position it is flush with the bottom of the pipe. The calorimeter C is attached to the perforated nipple F. The calorimeters are placed at some distance from an elbow or bend, so that if there is moisture in the steam it tends to run along the bottom of the pipe. This moisture will

flow into the nipple D and collect in the separator G. Nearly all the moisture may sometimes be drawn out in this way, and if the calorimeters B and C indicate dry steam, the weight of moisture collected in G represents the entire moisture in the steam. The three calorimeters are all covered in the same way to diminish radiation, and the normal reading of the thermometers I and J used in the calorimeters B and C can ordinarily be obtained by placing them in the calorimeter A. The perforated nipple F serves to show that there is no moisture distributed through the steam, and in the case of a sudden belch of moisture it will indicate the same. Barrus calorimeters were used in our tests, and the calorimeter A, combined with the separator G, forms in reality a Barrus Universal Calorimeter. With a prop-

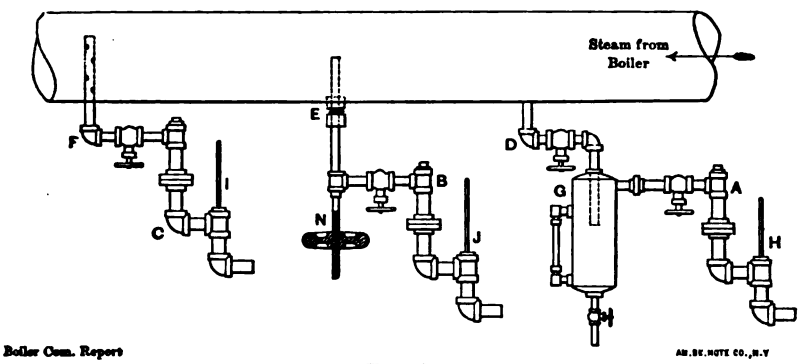


FIG. 8.

erly constructed separator, the steam passing through the calorimeter A will be practically dry with as high as sixty pounds of moisture drawn from the separator per hour, and, until this limit is exceeded, the normal readings of the thermometers used in the calorimeters B and C may be obtained by placing them in the calorimeter A, as has already been stated.

In some cases the calorimeter C is omitted and the amount of moisture is determined by means of the separator, with the adjustable nozzle at E and the separator and calorimeter A.

The percentage of priming P for the steam passing through the calorimeters B and C is given by the formula,

$$P = \frac{48}{L}(N - T),$$

where

P = the percentage of priming;

N = the normal reading, in degrees Fahrenheit, obtained by placing the thermometers in A;

T = the reading when placed in either B or C;

L = the latent heat at the pressure of the steam in the steam main in British thermal units per pound.

It is best to employ the normal reading, as Mr. Barrus recommends, in calculating the moisture corresponding to the readings of a throttling calorimeter, and not the formula given in Appendix XV. of the Code; for if the formula given in Appendix XV. is used, the mercury thermometer used to measure the temperature of the steam, after passing through the orifice, must be corrected for the error produced in not heating the entire length of the stem, and must also be corrected to make the readings correspond with those that would be given by an air thermometer. The radiation of the calorimeter must also be determined by a separate experiment, and allowed for. When the normal reading is taken, as Mr. Barrus recommends, all errors of radiation and corrections for the thermometers are eliminated.

The normal reading should be obtained either by connecting the calorimeter to a vertical nipple, with no side holes, which projects upward in a horizontal steam-pipe, in which the steam is in a quiescent state, or it should be obtained by connecting the calorimeter to a separator which is known to remove all the moisture. The normal reading should not be determined when the calorimeter is attached to a horizontal nipple with side holes, placed in a vertical pipe, because should this be done the readings may be low on account of moisture, which may fall through the steam and cling to the nozzle, and, finally, be drawn into the calorimeter.

The results given by a throttling calorimeter cannot be relied on within one-fifth of one per cent., because experiments have shown that the quality of the "dead steam" used in obtaining the normal readings may vary by this amount.* As the quality of the "dead steam" may not be that of the steam used by Regnault in his experiments, there may be a still greater error. When the formula given in Appendix XV. of the Code is used, the probable error is not eliminated, for a study of Regnault's

* *Transactions*, Vol. XVI., p. 466.

Experiments shows that the value used in the formula for the specific heat of superheated steam may be slightly in error for the conditions involved in a throttling calorimeter. Experiments have shown that the two methods of computing the moisture agree within one-fifth of one per cent. when the proper corrections are made for radiation, and when the temperatures are reduced to the equivalents by an air thermometer.* These experiments were made at the single pressure of 80 lbs. per square inch above the atmosphere, and it has not been shown that the two methods agree within this amount at all pressures, but as there should be no discrepancy provided the specific heat factor remains constant for the conditions involved, it is probable that the two methods agree very nearly with each other at all pressures.†

What is needed, are tests to compare the quality of "dead steam" with the quality of the steam used in Regnault's Experiments, and until this is done throttling calorimeter results cannot be relied upon within one-fifth of one per cent., and may be in greater error than this amount.

---

* *Transactions*, Vol. XVI., p. 460.

† It must not be inferred from this that the author considers the specific heat of steam to be the same at all pressures. On the contrary, he has made experiments which show that this is not the case.

LIST OF RULES FOR CONDUCTING BOILER TRIALS, CODE OF 1899.

ARTICLE		PAGE
I.	Determine Specific Object of Trial	38
II.	Examine the Boiler	38
III.	Notice the General Condition of the Boiler	38
IV.	Determine the Character of the Coal	38
V.	Establish the Correctness of all Apparatus	39
VI.	See that the Boiler is Thoroughly Heated	39
VII.	Prove Boiler Free from Leaks, etc	40
VIII.	Duration of the Test	41
IX.	Starting and Stopping a Test	41
X.	Standard Method of Starting and Stopping a Test	41
XI.	Alternate Method of Starting and Stopping a Test	42
XII.	Uniformity of Conditions	42
XIII.	Keeping the Records	43
XIV.	Quality of Steam	43
XV.	Sampling the Coal and Determining its Moisture	44
XVI.	Treatment of Ashes and Refuse	45
XVII.	Calorific Tests and Analysis of Coal	46
XVIII.	Analysis of Flue Gases	46
XIX.	Smoke Observations	47
XX.	Miscellaneous	47
XXI.	Calculations of Efficiency	47
XXII.	The Heat Balance	48
XXIII.	Report of the Trial	48
—	Complete Form of Report	49
—	Short Form of Report	53

LIST OF APPENDICES TO CODE.

NO. OF APPENDIX			PAGE
I.	Relative Weights of Water and Fuel	C. E. E.	55
II.	Object of the Test. (I., 1885 Code)	J. C. H.	56
III.	General Observations. (II., 1885 Code)	C. T. P.	56
IV.	Precautions to be Observed in Making a Boiler Test. (III., 1885 Code)	C. E. E.	57
V.	Weighing the Coal. (IV., 1885 Code)	J. C. H.	60
VI.	Weighing the Coal. (V., 1885 Code)	C. T. P.	60
VII.	Weighing the Water. (VI., 1885 Code)	J. C. H.	61
VIII.	Measuring the Feed Water. (VII., 1885 Code)	C. T. P.	61
IX.	Keeping Time of Observations. (VIII., 1885 Code)	J. C. H.	62
X.	Description of Boiler. (XXIII., 1885 Code)	C. E. E.	62
XI.	Determining the Moisture in Coal	W. K.	63
XII.	Proximate Analyses of Coal	W. K.	65
XIII.	Coal Calorimeter	G. H. B.	66
XIV.	Comparative Calorimetric Tests of Coals	W. K.	68
XV.	Determination of the Moisture in the Steam	W. K.	70
XVI.	Correction for Radiation from Throttling Calorimeters	G. H. B.	72
XVII.	Combined Calorimeter and Separator	G. H. B.	73
XVIII.	Corrections for Quality of Steam	C. E. E.	74
XIX.	The Quality of Superheated Steam	G. H. B.	77
XX.	Efficiency of the Boiler	W. K.	78
XXI.	Distribution of the Heating Value of the Fuel	W. K.	80
XXII.	Observation Blanks. (Amendment to XXIV., 1885 Code)	C. E. E.	82
XXIII.	Horse-power. (XXV., 1885 Code)	J. C. H.	82
XXIV.	Steam Units. (XXVI., 1885 Code)	C. E. E.	83
XXV.	Discrepancy between Commercial and Experimental Results	C. E. E.	85
XXVI.	Recording Steam Gauge. (IX., 1885 Code)	J. C. H.	86
XXVII.	Pyrometer. (XIII., 1885 Code)	C. T. P.	86
XXVIII.	Draft Gauge. (XIV., 1885 Code)	J. C. H.	87
XXIX.	Draft Gauge	G. H. B.	88
XXX.	Draft Gauge	W. K.	89
XXXI.	Sampling Flue Gases. (XVI., 1885 Code)	J. C. H.	91
XXXII.	Computation of the Weight of Chimney Gases from the Analysis by Volume of Dry Gas	W. K.	92
XXXIII.	The Orsat Apparatus for Analyzing Flue Gases	G. H. B.	95
XXXIV.	Smoke Measurements	G. H. B.	96
XXXV.	The Ringelmann Smoke Chart	W. K.	97
XXXVI.	Starting and Stopping a Test	W. K.	99
XXVII.	Starting and Stopping a Test	G. H. B.	101
XXXVIII.	Chart Showing Graphically the Log of a Trial	G. H. B.	103
XXXIX.	Continuous Determinations of Carbonic Acid in Flue Gases,	G. H. B.	103
XL.*	Measuring Radiation from Certain Types of Boilers	R. S. H.	103
XLI.*	Determination of the Moisture in Steam Flowing through a Horizontal Pipe	D. S. J.	106

* Contributed by members of the Society and accepted by the Committee for publication in the Appendix.

No. 828.*

DISCUSSIONS

UPON THE

PROVISIONAL AND AMENDED DRAFTS OF THE REPORT OF THE COMMITTEE ON THE REVISION OF THE CODE OF 1885, RELATIVE TO A STANDARD METHOD FOR CONDUCTING STEAM-BOILER TRIALS.†

DISCUSSION AT NEW YORK MEETING, DECEMBER, 1897.

Mr. R. S. Hale.—In Article XXII. of the Code, the "Heat Balance" items, though convenient, are rather illogical. Items 2 and 3 contain both latent heat, which properly belongs to them, and also a certain amount of sensible heat which more properly belongs to item 4.

Item 6 is too broad, and would encourage engineers to omit several important calculations. I should add items as follows:

6. Radiation measured by increase of boiler-room temperature. Pounds air per pound combustible times .24 times difference of temperature between external air and air entering ash-pit.

7. Radiation into still air as computed by radiation test or from experiments on boiler coverings.

8. Loss due to heating moisture in air. Pounds moisture per pound of air times pounds of air per pound of combustible, times 48 times $(T-t)$.

9. Loss due to counting the ash carried over the bridge-wall as

---

* Presented at the New York meeting, December, 1899, of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

† The Committee presented the first draft of its report in December, 1897, at the New York meeting; as amended in the light of discussions then presented, it was presented anew at the Annual Meeting of 1898; as again amended it was again presented and discussed at the Washington meeting of May, 1899. It is the wish of the Committee that final action upon its work might be taken at the Annual Meeting of December, 1899.

In presenting the final copy of the report, in December, 1899, the sub-committee has approved many of the suggestions originally submitted in the discussion, and changed the Code accordingly. Portions of the discussion relating to these suggestions have therefore been omitted.

combustible. Proportion of ash thus carried over times heat value of one pound of combustible.

10. Loss due to unconsumed hydrocarbons.

11. Loss due to soot or smoke.

12. Unaccounted for. This item includes items (give the number of each) not determined in this particular test.

In regard to item 9, referred to above, this is computed as follows from the analysis of the coal and the ash, and from the weight of refuse. Supposing the analysis of the coal shows 3 per cent. of earthy matter, or 30 pounds per 1,000. Supposing the refuse is 4 per cent. of the coal, and that an analysis of the refuse shows that it is 50 per cent. earthy matter and 50 per cent. combustible. That comes out to 20 pounds of earthy matter in the refuse for each 1,000 pounds of coal fired. But as the analysis of the coal showed 30 pounds, we see that 10 pounds per 1,000, or 1 per cent. of what we have counted as combustible, was really earthy matter carried beyond the bridge-wall.

The determination of this item is unimportant of itself, but is very important by furnishing a check on the accuracy of the sampling. If, as I confess has happened to me more than once, the calculation shows that a negative amount of earthy matter has gone up the chimney, it is obvious that an error has been made in sampling.

In the formula in the footnote under the heat balance, I should prefer to use the molecular weights 44, 32, 28, etc., rather than their submultiples 11, 7, etc. They are a great deal easier to remember as molecular weights than as entirely independent numbers, and the calculation is as easy. I should like to see several items added to the report of the trial. Under item 2, both the actual duration from start to stop and the equivalent duration computed as directed should be given.

Item 15 should be temperature of air entering ash-pit, or this should be given in addition to boiler-room temperature.

Item 17 should be divided: temperature of steam as computed from pressure and temperature as measured.

In regard to the formula for determining the calorific value of the coal, the Germans have adopted an official formula which is in British units $14{,}400C + 52{,}200\,(H - O_8) + 4{,}500S - 1{,}080H_2O$, and Mr. C. J. Wilson, who is probably the best authority on the subject of coal calorimetry, is using $14{,}540C + 52{,}200H + 4{,}000S$.

In each case they subtract the heat of evaporation of the H_2O formed from the H in the coal. If this method of subtracting the heat of vaporization of the H_2O in the gases be retained in accordance with Continental and English practice, then when a calorimeter test is made of the coal, but no analysis, it will be necessary to subtract from the calorimeter test a percentage depending on the class of coal which can be easily computed within the limits of error of the calorimeter trial.

In regard to sampling the coal, or rather in regard to quartering it down after sampling it, Mr. H. J. Williams, the Boston chemist elsewhere referred to in the report, has devised a very pretty method, which he has given me permission to describe. A set of long, rather deep boxes are set in a framework parallel with each other, so that the spaces between them are exactly equal to their width. Coal can be shovelled in, and until the boxes are filled, one-half exactly will fall into the boxes, and one-half will fall through, and these halves will be a fair average of the coal. The total having been thus treated, one-half may be thrown away, and the process repeated on the remainder, thus obtaining a fair sample one-quarter the size of the original, and by repeating the process (alternating with crushing the lumps) a fair sample may be obtained of any desired amount. Mr. Williams's own box is a small one for sampling coal after it has been crushed, but the same principle can be applied to larger boxes to take a whole shovelful or several shovelfuls of coal, and even the larger boxes need not be too large to be carried around to the boiler room, since the space in the boxes can be utilized for carrying other apparatus.

This same principle can also be applied without a special box, though not so conveniently. Suppose we have a heap of coal that has been shovelled over, and we wish to divide it into two equal parts that shall be a fair average. The ordinary method is to shovel half to one side and half to the other, but in doing this it is hard not to get more lumps in one half than in the other. The method according to the above principle is to take a box with one side made of comparatively thin boards. Take a shovelful anywhere from the pile of coal, and place the shovel on the edge of the box so that half the coal falls into the box and half outside. Repeat until all the pile of coal has been used, when half the coal will be found in the box and half outside, and the halves will be fair averages. The chief precaution

necessary is not to fill the box so full that any of the coal that belongs inside rolls down outside, or *vice versa*. The process can be repeated (alternating with crushing the lumps) until the sample is of suitable size.

Professor Webb (abstract) described the draft gauge which he illustrated in vol. iii., page 787, Fig. 230, and criticised the hanging tin-can plan, because the spring would be likely to accidental change and cannot be a standard. The spring if not too long will not stretch uniformly; the can, unless quite thick, will be liable to change of shape; if the can is thick there will be an error due to the water displaced by the can. An error will be introduced by the way the can hangs; unless a long spring is used, the range of pressure which it indicates will be limited.

Professor Carpenter described the Péclet draft gauge. Discusses the use of a differential manometer described by Péclet.

Mr. Rockwood emphasizes the possible confusion in understanding the bearing of the Appendices on the Code and to each other. In steam-engine testing we are concerned with total weight of water, the total weight of separator condensation, the total weight of jacket water, or condenser water. In boiler testing a relatively small portion of the total coal burned is made the basis on which to reckon efficiency during test. A relatively small portion of waste gases is taken to represent the whole. The moisture is determined on a small sample. Steam calorimeters rely on a small sample. He emphasizes further the necessity to decide on the maximum reasonable error allowable or to be expected in every branch of boiler testing. Thinks the Code is a scientific code in its present form, and not as good for commercial life where it departs from the old report.

Mr. Allan Stirling (abstract).—"The new Code should take effect in 1900. The unit of capacity should be pounds of water evaporated per hour, and suggests a less unit than thirty." Emphasizes necessity for average results; most horizontal heating surfaces are not clean when actually used; both when dirty, as well as clean, emphasize the advantage of vertical curved tubes.

Mr. Gale (abstract) criticises the method of determining the heat value of the fuel, and puts on record the opinion that it is impossible by any formula to deduce the calorific power from an analysis giving ultimate chemical composition, because the car-

bon, hydrogen, and oxygen do not exist in the coal in the same condition in which their heats of combustion are determined separately. Believes the calorimeter test is the old reliable method; at present prefers the oxygen calorimeter. Would have the first paragraph of Article XVII. of the Code amended, to read: "The quality of the fuel should be determined, if possible, by a careful heat test." The second paragraph he would have as it is. In the third paragraph he would substitute for the words "should be obtained," the expression "may be obtained approximately." Would strike out the fourth paragraph.

Mr. Henning suggests that the Committee should prescribe some formula or method whereby smoke prevention methods by steam jets, usual where imperfect composition is to be expected, should be taken account of.

Mr. Cary approved the Berthelot bomb as a coal calorimeter. Emphasized greater care in stating furnace peculiarities. Suggested the necessity for a statement of furnace efficiency apart from the boiler efficiency, and the significance of this with respect to coals west of the Alleghanies.

Referred also to special settings, grates, and stokers. Thought the relative value of water heating and superheating surface of boilers should be considered. Suggested a smoky fire, or the use of a candle outside the wall as means for determining leakage through bricks. Says no test with a water meter should be accepted. Criticises the arrangement to have water of condensation not returned back to the boiler. What is the expert to do when the plant is piped that way? Discusses the use of smoked glasses in a telescope for determining percentage of smoke.

Charles H. Manning.—Recommended seventy-two hour tests, but never less than ten. It is particularly unfair to the horizontal tubular, which is growing better from Monday to Wednesday, but then runs down.

H. W. Spangler.—On page 5, Article IV., the statement is made that, "For tests of the efficiency or capacity of the boiler, the coal should, if possible, be of some kind which is commercially regarded as standard." For purposes of comparison with other boilers, this is probably right, but for the purpose for which many boilers are tested it is surely wrong. A man buys a boiler to do certain work, and he proposes to use a certain definite kind of coal which is in common use in his

neighborhood, and which is probably, in the long run, the cheapest coal for him to burn. Contracts are often made so that the boiler is required to develop a certain capacity and a certain efficiency, using the coal that it is proposed to burn, and not any standard coal. That is, in Philadelphia, for instance, no one would think of using good anthracite egg coal for steam-raising purposes, and the test of a boiler with this would simply fool the owner; whereas a test with anthracite buckwheat, which is a very different thing, or a mixture of small anthracite and bituminous slack, which the owner expects to burn, is the coal on which he wishes to know the efficiency and capacity of his boiler. That this question is of some moment I know, as a boiler-maker recently insisted that his boiler would develop the capacity for which it was sold if he were allowed to use bituminous coal on the test. The contract required, under that portion of the contract relating to tests, that the economy on a smaller rating should be based on the burning of small anthracite, and in a different portion of the contract, that the maximum capacity, using pea coal, should be a certain amount. The contractor claimed that the A. S. M. E. Code justified him in his request.

In the matter of starting and stopping the test, it has always seemed to me that the standard method set down was about the worst that could be devised.

In Article IX, page 41, the present report says that "the condition of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure should be the same; the water level the same; *the fire upon the grate should be the same in quantity and condition; and the walls, flues, etc., should be of the same temperature.*"

In Article XII, "*In all trials made to ascertain maximum economy or capacity the conditions should be maintained uniformly constant.*" The above quotations should, I believe, be strictly adhered to.

Article X., page 41, says, however, "Remove rapidly all the fire from the grate, close the damper, clean the ash-pit," and so on. That is, the first step towards keeping the conditions uniform is to do something that never is done in a boiler, from the time it goes into use until it goes out again. The alternate method, given on page 42, is surely better than the standard

method, except from the fact that it is presumed that something is to be done with the estimated quantity of coal at the beginning of the test—and estimated quantities are difficult to determine. I believe the following method of procedure will give more accurate results, and will do away with a large amount of the objections which are made to both the standard and the alternate methods. The scheme is, on the face of it, a little more intricate than either of those in the Code, but it seems to me that it is the fairer.

Suppose we have a 100-horse-power boiler to test, the test to be run for ten hours, and to be started some time in the early morning. Give directions over night that the fires are not to be cleaned for at least six hours before the time the test is intended to begin, but that the boiler should be used at about its capacity, or at about the capacity at which it is to be run during the test. Before 7 o'clock, say, weigh out, for example, 400 pounds of coal (enough to run about an hour), adjust the water level to the point at which the water is to be carried during the test, adjust the steam dampers, outlet, and pump, so that the water level remains constant, and approximately the right quantity of water is going through the boiler. Have the fires cleaned, and note the time at which cleaning begins, say 7 A.M. Allow the fireman to use the 400 pounds of coal as he see fit, keeping the water level and the quantity of water going through the boiler up to the proper limit. The best control on the fireman is to allow him to keep the pressure at a given point. The quantity of steam taken from the boiler, and the quantity of water put into it, will adjust the fireman's work to the demands. The 400 pounds of coal will be about used up in an hour, but allow him to use it as he pleases, and as soon as he requires more coal, note the time he begins to use this, and call this the beginning of the test; say this is 8.05 A.M. Suppose the test is to run for ten hours. The test would then end at 6.05 P.M. At 5 o'clock weigh out the same quantity of coal as at the beginning of the test, and have him begin to clean his fires at 5 o'clock. Keep the water level and the quantity of water going into the boiler constant during the last hour and five minutes as it was during the first, and stop the test at 6.05 o'clock. The fire will then be in as near the condition as it was at the beginning of the test as, I believe, it is possible to get it. If the fireman thoroughly understands what he is expected to do,

there is no difficulty in having the last hour run practically identical with the hour before the test commenced. Make the time of the test so that a convenient cleaning time will come at the end of the test. The water rate is kept about constant during the last hour, and the boiler is changed with *all* the last lot of coal.

In Article III., page 38, unless a boiler setting is very leaky a candle will locate air leaks more satisfactorily than the use of smoky fuel.

Prof. D. S. Jacobus.—The report recommends that we neglect the heat lost through evaporating the moisture contained in the coal and the moisture formed by burning the hydrogen in the coal, in computing the efficiency of a boiler.

In my discussion on Mr. Dean's paper on the efficiency of boilers, presented at the Detroit meeting, in 1895, I stated that if we wished to determine the efficiency of a boiler as an absorber of heat, it would make the results for various grades of coal more directly comparable with each other to reduce the results for efficiency to the equivalent efficiency, if there were no moisture produced in the flue gases through burning the coal. To do this, we would have to subtract from the total coal burned the coal required to evaporate and superheat the moisture to the temperature of the escaping flue gas, to find the equivalent weight of dry coal, and employ the equivalent weight of dry coal in obtaining the efficiency. This would amount to the same thing as dividing the efficiency, if no moisture is allowed for by the quantity.

$$1 - \frac{Q_2 + Q_3}{H - (Q_4 + Q_5)}, \quad \ldots \ldots \quad (A)$$

where H is the total heat value of one pound of combustible burned under the boiler, and Q_2, Q_3, Q_4, and Q_5 the respective quantities numbered 2, 3, 4, and 5 in the heat balance on page 15; or the efficiency, E, allowing for all moisture would be

$$E = Q_1 \div H \left\{ 1 - \frac{Q_2 + Q_3}{H - (Q_4 + Q_5)} \right\}, \quad \ldots \quad (B)$$

where Q_1 is the first quantity given in the heat balance.

If the efficiency is calculated by allowing for all the moisture in the way that has just been described, we eliminate, as nearly as possible, all differences due to the quality of the coal burned,

and the efficiency thus obtained appears to me to be a better measure of the performance of the boiler, as an absorber of heat, than the efficiency obtained in the way recommended in the report.

Notwithstanding the more exact nature of the efficiency if all moisture is allowed for, and the ease with which the allowance can be made if there is a heat balance, I cannot but feel that the reasons given in the report for adopting the efficiency thereby specified show that it is a desirable unit. Even should we allow for all the moisture, the class of coal would have to be specified, for there are variations aside from the moisture tending to effect the efficiency, and if there is a need of specifying the coal, it appears to be best to reduce the calculations as much as possible and employ the efficiency recommended in the report.

In calculating the efficiency and in obtaining the heat balance, the heat value of one pound of combustible, to be rigorously exact, should be the heat of combustion of that part of the combustible consumed under the boiler, which may be slightly different from the heat per pound of the total combustible, as given by a calorimeter. This difference will be a very small one in most cases, however, and it is best not to complicate the report by allowing for it.

It may be desirable in some cases to introduce a separate item in the heat balance for the heating of the moisture in the air, which, although a small quantity, may often exceed the loss due to the moisture contained in the coal. This figure is readily obtained by employing a wet and dry bulb thermometer to determine the humidity of the air. If this loss is determined, it should enter the quantity (A) and the equation (B) and (C) in the same way as Q and Q_3.

There is a recommendation that when the indications of the calorimeter used in determining the quality of the steam show that the percentage of moisture is irregular, or occasionally in excess of 3 per cent., the results should be checked by a steam separator, placed in the steam pipe. This is in line with the results of experiments made by Professor Denton and myself. I would go further than this, however, and not allow for any moisture unless the total moisture was determined either by drawing it out of the steam, and weighing it, or by throttling the whole amount of steam leaving the boiler, and calculating

the moisture from the temperature of the steam after throttling, which would amount to passing the entire mass of steam through a throttling calorimeter.

Mr. William H. Bryan.—After further study of the proposed Code for conducting boiler trials, as finally revised by the Committee, and in connection with the appendices and original discussion, I beg to submit the following recommendations:

1. Page 36, paragraph 3. That the capacity of a boiler be expressed in terms of the "number of pounds of water evaporated per hour from feed water of —— degrees Fahr. temperature, into steam of —— pounds gauge pressure, or its equivalent." This carries with it the proposed conditions of operation, while for purposes of comparison it is readily reducible to "from and at 212," if desired. The use of the term "or its equivalent" provides definitely for some possibility of fluctuation of the feed temperature and pressure, and does not leave this to be taken for granted.

2. Page 37, paragraph 3. That draft be preferably stated in tenths of an inch; and that the draft at which a boiler shall be expected to develop one-third more than its rated capacity be stated at .6, instead of .5. This is, in my opinion, of great importance—particularly with low-grade fuels.

3. Articles X. and XI. of the Code. That the "alternate" method of starting and stopping a trial, Section XI., be made the standard or preferred method, as being less liable to error than the "standard," and as being the only method consistent with the maintenance of uniform conditions, as required in Article XII.

4. Article XV. That a clearer distinction be made between "characteristic" moisture and "surface" or "accidental" moisture in the coal. In determining the weight of dry coal consumed, the weight of the accidental moisture should be deducted, but the characteristic moisture should be retained. A much better plan is to air dry in advance the entire lot of coal to be burned, so as to remove all accidental moisture.

5. Use the word "trial" instead of "test" wherever it occurs in the Code and Appendices, to distinguish an evaporative trial of a boiler from the physical test made on the same boiler by pressure, hammer, or inspection.

Mr. Wm. O. Webber.—I have looked over the report of the revised code of boiler tests and approve of it very strongly. I

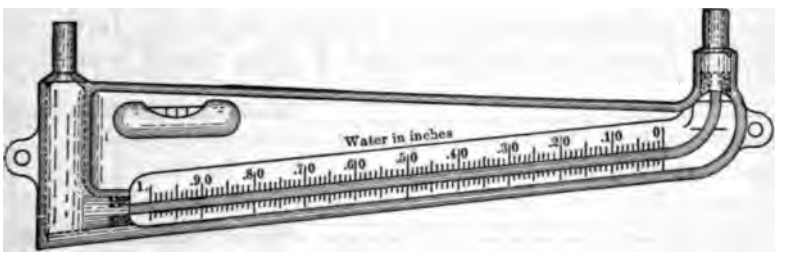
think that there are some criticisms to be made in the way of restricting the short code to one of possibly two expressions regarding efficiencies. I think it is a great mistake to give some men a half-dozen efficiencies based on different premises, and half a dozen different evaporations based on different bases, rather than one of each based on a generally accepted basis; that is, I think the efficiency should be confined to the efficiency of the boiler, including the grate, and the evaporation to the evaporation from and at 212 degrees per pound of combustible.

The heat balance, or distribution of the heat value of the combustible, proposed by the Committee, necessitates an ultimate analysis of the coal used for each individual boiler test. This is perfectly right and proper if such tests are being made to determine the relative value of the different grades of particular kinds of coal; but in a great many cases, where tests are simply made to determine the efficiency of a boiler plant, or the advantage or disadvantage due to the application of some particular device, neither party would be willing to pay for an ultimate analysis of the coal being used. I would, therefore, suggest that some standard be adopted for the heating value of such coals as are generally used here in the East, so that if, for instance, such a test was being made, using George's Creek Cumberland Coal, we might use some standard analysis of this particular coal from which to obtain our heat balance, and so on for other well-known grades and classes of coal; or, as an alternative, propose some standard method by which the proximate analysis of coals in a coal calorimeter could be used, from which a proportional ultimate analysis might be deducted.

Referring to that part of the report covering draft gauges, I wish to call your attention to what is known as the Eames Differential Draft Gauge (Fig. 9), which is made by Mr. Lewis M. Ellison, of Chicago. This gauge is made of aluminum, with a scale engraved directly in the metal, and is capable of measuring 2 inches of water, either vacuum or pressure. It consists of a glass tube mounted upon the aluminum base, one end of the tube being fixed into a vertical cylindrical chamber, the bottom line of the tube extending slightly over 10 inches, at such an angle to the horizon that a point 10 inches beyond the lower end of the tube, where the end enters the vertical cylinder before alluded to, is just 1 inch above the other end. The tube is then pointed upwards, and is fastened into a nipple on top of the

casting. The vertical part has two (2) graduations upon it at half-inch and one inch respectively above the zero point upon the near end of the tube. The 10-inch space between the zero point and the lower end of the tube is then divided into ten equal parts, which are then subdivided into ten more equal parts, therefore giving immediate reading to the one and one-hundredth of an inch. This can be readily subdivided by the eye so as to read very closely to one-thousandths.

This tube, when filled with a special non drying petroleum oil to the zero point before referred to, will give readings not ex-



Report Boiler Test Com. EAMES DIFFERENTIAL DRAFT GAUGE.

FIG. 9.

ceeding a draft equal to one inch of water. If it were desirable to register drafts or pressures above this point, by filling to the first mark above the zero point it will give readings to one and a half inches, and if filled to the second mark above the zero point it will give readings to two inches, adding the additional half-inch and one inch to the readings on the length scale.

The aluminum casting carrying the gauge is also provided with a fixed horizontal levelling bulb, so that it may be readily levelled. I have had one of these gauges for nearly a year now, and have used it a great number of times. I have found it perfectly reliable, very satisfactory, and apparently very accurate.

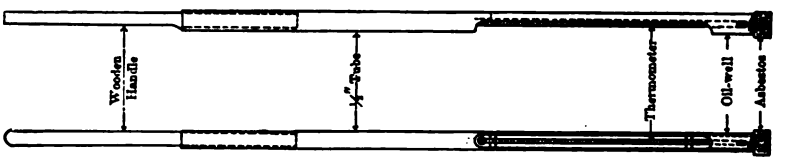
Members of the Society can obtain them from Mr. Ellison at quite a reasonable discount from the list price, and it seems to be such a reliable instrument, at a fair price, within the reach of all members, that I think it my duty to call attention to it.

The whole apparatus is not over 1 foot in length by 4 inches in width, and about three-quarters of an inch thick, and is very light, and can be very readily transported.

I note what the Committee on Tests say in regard to methods

of ascertaining the temperature of escaping gases, referring to the two Appendices of the 1885 Code, Nos. 12 and 13, by J. C. H. and C. T. P. respectively.

I hope, if any of the members have discovered any better methods of recording these high temperatures, they will give the Society the benefit of them. For my own part, I have only been able to evolve a simple bit of apparatus to facilitate the use of a mercury thermometer recording to 700 degrees Fahr. to this purpose. This device (Fig. 10), consists of a piece of ½-inch iron or brass tubing, with a cap upon the lower end, and a longitudinal slot of about 12 inches, starting about 3 inches above the capped end and extending one-half way through the tube. In the well that is formed on the lower end I have placed some loose



Device for Inserting Thermometer into Uptakes to obtain Temperatures of escaping Gases.

Report Boiler Test Com.

FIG. 10.

asbestos, and then filled this tube with cylinder oil, then placing two small strips of asbestos paper transversely around the inner periphery of the tube in the 12-inch opening. Lay the thermometer on this asbestos with the bulb projecting downward into the oil bath.

The total length of the tube from the bottom end is then made sufficiently long to project half way through the ordinary uptakes from the boilers, which would be about 2 feet. Into the pipe at this point is then inserted a piece of hard wood to serve as a handle. This I have found very convenient, as it prevents the radiation of heat up the tube to the observer's hand. I have usually flattened the upper side of the wooden handle so as to prevent turning the tube upside down, and so inadvertently dropping the thermometer out.

If, however, some form of mercury thermometer could be devised by which the climbing up and inserting of this apparatus, which I have just described, into the fuel, and having to brush the soot from the thermometer before being able to read it, could be prevented, so that the observer could take the read-

ings from the boiler-room floor, it would be a great advantage and save a good deal of physical labor.

I also wish to add my testimony to that of the Committee in favor of the Orsat apparatus for the analysis of flue gases, which is very compact, simple, and easy to use. The only criticism which I have to make against it is that it is very fragile and easily broken, which it seems to me could be easily remedied by making the U tubes of a little heavier glass, and mounting the whole apparatus in a rather more substantial box than that in which it usually comes. I think that if the Society would call the maker's attention to some of these defects it might be the means of getting a more substantial piece of apparatus, which could be handled without the present risk of breakage.

I hope that the present report will be accepted by the Society and given its official sanction, so that it may obtain the standing which it deserves, as it represents what we are now very much in need of; that is, some standard method of making and recording boiler tests which will be accepted by every one as a standard method.

E. H. Peabody.—No one is in a position to appreciate more greatly the amount of thought and study necessary to prepare a code for a standard method of making boiler tests than the engineer whose vocation it is to make such tests; and I wish, in common with many others, to express my sense of appreciation of the work done by this Committee. The report, however, appears to me to be open to criticism on three points, namely:

1. The determination of moisture in steam.
2. The "wood fire start" or "standard method," paragraph IX.

To first discuss the latter point: The Committee has recommended two methods for starting and stopping boiler tests, the "standard method" and the "alternate method." The point I wish to make is that the standard method introduces a considerable error, and that only the alternate method should be used. To support this assertion I give the figures below, which came in the nature of a surprise to the writer, who had followed the standard method in many tests without ever questioning its accuracy. The figures were obtained as follows: Two tests were made on a water-tube boiler, a different grade of bituminous coal being used in each. The standard method was followed, except that the fresh wood fire was lighted immediately

after hauling the preliminary fire without waiting to clean the ash-pit, which was done a little later. In the course of half an hour, when the fire was in good condition, a flying start was made for *capacity*, and a definite rate of combustion being desired, the floor was cleaned, the thickness of fire noted, and thereafter a fixed amount of coal weighed out each hour and the blast so regulated as to burn that amount per hour. This fixed amount of coal each hour gave a ready basis for estimating the economic evaporation during the test, but on burning the fire down at the end as usual it was found that the total figures by the standard method showed a much poorer economy than the preliminary estimate. This loss in economic evaporation occurs to every test made by this method, and is due to the greatly impaired economy during the building up and the burning down of the fire at the start and finish, and may amount in some cases, as shown below, to an error of over 4 per cent. in a ten-hour test. This is much in excess of any error attaching to the alternate method when properly followed, and for this reason the latter is better, and should be adopted as the standard.

FIGURES SHOWING ERROR DUE TO STANDARD METHOD.

Date of Test, '97.	July 22.	July 23.
Water evaporated per pound coal from and at 212, by Standard Method	7.91	8.17
Water evaporated per pound coal from and at 212, during intermediate period of good fires	8.30	8.90
Percentage of Error due to Standard Method—test 6 to 7 hours	4.93	8.93
Percentage of Error due to Standard Method in 10 hours (estimated)	2.09	4.34

Entries in the general log ought also to be made dependent on the rate of combustion and evaporation, and I propose that an entry be made for each 10 pounds of coal burned per square foot of grate, which would be equivalent to half-hourly readings for ten hours.

Referring to the matter of calorimeter tests of steam, the Committee recommends the use of the throttling calorimeter, but does not settle the question of whether or not allowance is to be made for radiation in the instrument itself. Mr. Kent gives Professor Peabody's formula, and Mr. Barrus describes his well-known "calibration method." Both these methods are extensively used, and they not only do not agree within Mr. Kent's proposed limit of accuracy, "one-half of one per cent.," but may differ by more

than one per cent. This is shown by the following figures, which are merely the "normal readings" obtained by the Barrus method worked out by the theoretical formula given by Professor Peabody. The tests were chosen at random from a number, including some by such men as Charles E. Emery and Jay M. Whitham, and represent the best practice:

PER CENT. MOISTURE SHOWN BY BARRUS NORMAL READINGS.

Heisler	Calorimeter	1.27	per cent.	moisture.
"	"	1.09	"	"
Peabody	"	1.05	"	"
Barrus	"	.92	"	"
"	"	.52	"	"
"	"	.57	"	"
"	"	.91	"	"
"	"	.46	"	"
"	"	1.06	"	"

These calibrations were all made with dead steam, and the moisture indicated is due either to radiation entirely or to radiation plus some moisture possibly present in the "dead steam." Whichever supposition is correct, the two methods would differ by the amounts given.

Professor Jacobus has made experiments that show "dead steam" to contain less than one-fifth of one per cent. of moisture. If this is the case, the Barrus calibration method when properly followed is correct within a limit of error of one-fifth of one per cent., and as this method corrects for all radiation losses in the instrument, including radiation from thermometer cups, and from the thermometers themselves, and for all errors due to careless covering, etc., the method is well worthy of being adopted as the standard for all moisture tests with all forms of throttling calorimeters. There is an "if" in the proposition, but this might easily be eliminated by experiment.

R. C. Carpenter.—In referring to heating values of coal as given by a calorimeter, and as calculated from Dulong's formula as given by W. K., on page 69, in reference to coal No. 2, from New River, West Virginia, a considerable difference will be noticed as given for the heating value per pound by the several calorimeters and by the analysis by Williams. In general, the calculations from the analysis should give higher results than the determination by the calorimeter, since most errors which are made with the analysis

tend to increase the calculated values, while those made with the calorimeter tend to diminish these values. In this case, however, the results with the Carpenter calorimeter give 15,200 heat units; that calculated from an analysis by Williams gives 14,452 heat units. On referring to notes of the test made with the Carpenter calorimeter, it was found that three samples were tested at different times, and the result of the extreme observations were only one-third of one per cent. different from that recorded. This coal contained slightly over one per cent. moisture, so that the average value per pound of dry coal is computed at 15,350 British thermal units. Mr. C. H. Benedict, chemist at Cornell University, made a determination with the following result:

Per pound of Dry Coal:

Carbon	85.07 per cent.	Calculated Heat Values, 15,215 B. T. U. per lb.
Hydrogen	5.01 "	
Ash	4.71 "	
Nitrogen	0.82 "	
Sulphur	0.30 "	
Oxygen	3.79 "	

It is, of course, quite possible that the difference of heating values shown may be due to a difference in sample furnished the different laboratories; the difference in results, being nearly 5 per cent., is greater than should exist in the determinations, provided careful work be done in all cases.

Carpenter's calorimeter, as now made, is of the form shown in the annexed figure, the heat being determined by the rise in the attached water column, the general principle of the instrument being that of a large water thermometer. It is fully described in vol. xxvi. of the *Transactions*.

The general form of the result sheet, as proposed by the Committee, seems, on the whole, to be excellent, and to meet in a satisfactory way all requirements. For general use, however, it would seem to me better to omit items from 37 to 42, relating to the ultimate analysis of dry coal, for the reason that this work must be done by a chemist in a chemical laboratory; it is a very difficult operation, and probably will not be used by engineers except at rare intervals. The heat balance should, I think, find a place in the ordinary table of results, and so should the analysis of the flue gases, for the reason that both give important information in relation to the test, and there are no good reasons why they cannot be filled out for each test.

I would add to the table of results the values obtained in the flue-gas analysis, since such results are of essential value in determining the character and amount of the chimney wastes. I would therefore advise that places be left in the table of results for the results of flue-gas analysis, instead of for the ultimate analysis of dry coal.

In the correction for radiation in the throttling calorimeter, the writer has recently adopted the practice of closing the discharge valve from the calorimeter and opening that supplying the instrument, and noting the reading of the thermometer; by comparing this with the temperatures given in a steam table, the correction for the thermometer can be obtained in the exact position as used. It will be found that the instrument will read from 0 to 5 degrees less than the true temperature of the steam, depending upon the amount of exposure of the stem of the thermometer. The quality is very easily computed by reference to the accompanying graphical chart, the temperature of steam being taken as explained when the discharge valve of the calorimeter is closed, the temperature in the calorimeter being taken when the discharge valve is open, the thermometer readings in both cases being corrected for radiation as explained. The practice of correcting the readings of the calorimeter, which I have seen recommended, by using as a standard a sample of steam drawn from a quiescent boiler, and calling this dry and saturated, I have found by practice may lead to an error of considerable amount. This was also the conclusion drawn by Prof. W. C. Unwin, in a report on the subject made to the Institution of Civil Engineers, January, 1895.

Considering the difficulty of obtaining a sample of steam which varies less than $\frac{1}{2}$ per cent. from the average, it seems quite unnecessary to take precautions in calorimeter work for obtaining readings accurate to $\frac{1}{10}$ of 1 per cent., as has been recommended in certain instances. Where the steam contains a considerable amount of moisture, the separating calorimeter (see figure) will be found to give accurate results, provided, of course, that an average sample of steam can be supplied. I fully concur, however, in the opinion stated by the Committee, that in the case where the steam contains considerable moisture a steam separator should be placed close to the boiler, and all the water possible should be trapped out. The sample for the calorimeter should be drawn from the pipe after passing the

separator, and the moisture, as determined by both calorimeter and separator, should be stated in the result. In any case, the determinations of the correction for radiation loss may be necessary.

In regard to the best method of making a flue-gas analysis, the writer would say that there are several forms of apparatus used for this purpose, and considerable difference of opinion is expressed by chemists as to the relative accuracy of each. The chemists of Cornell University consider Hempel's apparatus as more accurate than the Orsat, one reason being that in the Orsat apparatus a liquid reagent can only be used, is not very stable, and which often gives poor results, while in the Hempel solids as well as liquids can be used. Although doubtless very accurate, it is not portable. In the department of Mechanical Engineering, we have employed a form which is a modification of the Orsat, designed so that one can use the same reagents as the Hempel, but the burettes are arranged in a portable case, as in the Orsat. The burettes are, however, of a much stronger form than those used either in the Orsat or the Hempel, and the case can be readily and safely taken from place to place. The general form of burette and of the apparatus, as erected, are shown in the accompanying drawings.

I think the Society should give more elaborate directions for stopping a test by the standard method and of starting a test by the alternate method. In many boilers the condition of the fire affects the water level to a very great extent. As an instance, I recently took charge of a test of certain boilers, in which I found, to my dismay, that the water level could be changed fully 8 inches in height by merely changing the drafts of the furnaces, and extraordinary precautions had to be taken, which are not mentioned in either method, to insure uniformity of condition at the beginning and end. If the fire be allowed to burn low, as per the direction for the standard method, the water level would drop, and a correction of no small amount in some cases, and one which really had not been earned, would be put to the credit of the boiler. This may be very largely prevented by running the boiler one hour before the test, under the same conditions as the last hour of the test; that is, burning the same amount of coal and evaporating the same amount of water as during the last hour of the test. In the test referred to, such a plan had to be adopted to insure uniform conditions. The principal difficulty

with the standard method is that relating to stopping, quenching the fire, and correcting the results for unburned fuel, and this very difficult operation is passed over without comment in the report.

In the use of the alternate method the difficulty is largely in starting, and a preliminary hour not counted in the test, but in which water and coal are measured and run exactly as in the last hour, will be found of great help in judging the fires.

DISCUSSION AT WASHINGTON MEETING, MAY, 1899.*

Col. E. D. Meier.—Mr. President, I would like to say, first, that I think the Committee is to be congratulated and deserves a vote of thanks for the most excellent and entirely impartial manner in which they have completed their arduous task; and feeling as I do about it, knowing how difficult it is to get any further amendment to a code after it has once been established, I am somewhat at a loss how to proceed. But it seems to me that as the Committee itself has worked in the direction of simplification as much as possible, the first thing I desire to propose would probably meet with their approval without any discussion, and it is this: On page 36 they refer to the "unit of evaporation" as well established. It was accurately defined in the code of 1885 and has been used by engineers ever since, and it seems to me that it deserves to be put into the code just as "*The Unit of Evaporation*" without the necessity of constantly re-describing and re-defining it, just as much as the British thermal unit. If we read anywhere in a contract or in a test the simple initials "B. T. U.," everybody knows it without our explaining what a British thermal unit is. I think it would be very advisable and save a great deal of time, and that it is justly due to both committees, to let us use simply the initials "U. E." to represent the unit of evaporation, and have the definition put in, if you please, once for all. Then in the short form which the blank for a test must always have—that is, the blank which is provided for putting down the records of a test—let us simply say "U. E.," and not so many pounds evaporated from and at 212 degrees. Just let us

* An extended discussion by Prof. C. V. Kerr, advocating the Berthier method of calorimetry, was contributed at this meeting and will be found as a separate paper, as No. 838 in Volume XXI. It was felt by the Committee that the subject of the Berthier method should be separately discussed, rather than that it should be included in the debate upon the features of the Code for Testing Boilers.

understand the initials "U. E." to mean that once for all, and have the definition stated only once in the code.

Then on page 37, in stating the rated capacity of a boiler, they say very justly that a boiler should develop at least one-third more than the stated capacity, but they state "the available draft at the damper, unless otherwise understood being not less than $\frac{1}{2}$ inch water column." I think that should be made *at least* $\frac{6}{10}$ inch. Probably most of the members of the Committee were more familiar with the Eastern coals; but when you come to such coals as have to be used in the great manufacturing districts of the Mississippi Valley, and still farther west, in Colorado and in California, you meet conditions where it may be sometimes that, with the best devices for promoting the combustion, it is impossible to get one-third more with a draft of only half an inch. I think that should be made $\frac{6}{10}$ of an inch. The Committee has considered that question very thoroughly in another place, where they say that wherever a certain coal is specified, a coal which has more ash and more moisture shall not be used, showing that they do lay stress on that. But it is a great deal easier to insist on $\frac{6}{10}$ of an inch draft than to always get exactly the kind of coal which has been specified. Sometimes the party who furnishes the coal may be doing the best he can and get somewhat more in ash and in moisture; then the unfortunate contractor would at least have the $\frac{6}{10}$ of an inch draft; he can get along with that, but he cannot with half an inch. I would like that referred back to the Committee to increase it to $\frac{6}{10}$ of an inch.

Then on page 42 they reiterate the very sensible and useful provision of the former code that when the water level is not the same at the end of the test as at the start, a correction should be made by computation, and not by operating the pump after the test is completed. I would suggest to the members of the Committee whether it would not be well to add a note there referring to the care which must be used in this computation. I have seen such computations made by just calculating the amount of water which would fill up this space, figuring first the space in the boiler which is left between the two water levels and then calculating the amount of the water level on the basis of the weight of the water at the known temperature. Now that is not correct, because there is present in that boiler besides water at that temperature a large amount of steam, and

in order to calculate that correctly, some allowance should be made for the difference in the weight of the mixture, which is a good deal less than that of water at that temperature. If colder water is pumped in, the steam bubbles collapse and their space is filled by this colder and heavier water. This would be incorrect; and just so an estimate based on filling the space between water levels with solid water is too great by the space occupied by the steam bubbles in the water.

William H. Bryan.—Several designs of draft gauge having been submitted, I take the liberty of contributing a drawing showing a gauge which I designed recently for permanent use in a central lighting station in St. Louis. It consis's essentially of a glass U tube, lying in a plane making an angle of 1 in 10 with the horizontal. This tube is supplied with water, filling it about half way. One end is open to the atmosphere, and the other is connected by a small rubber tube to a manifold underneath. This manifold may have as many outlets as desired, eight being supplied in the present instance, besides one on the opposite end of the manifold, which is ordinarily used for opening to the atmosphere for adjustment.

In the present case, four of these connections are carried to the spaces between the grates of the down-draft furnaces of four independent boilers, as shown by the cross on the drawings: one to uptake from two east boilers, another to uptake from two west boilers, another to chamber above induced-draft fan, and the last to base of stack. ¼-inch gas pipes were run from the draft gauge to each of these locations, enabling the draft at any of the eight points to be read by simply opening the proper petcock. The scale is movable, and when a reading is to be taken the thumb-screw is turned until the nearest even inch is brought to the position of the water on one leg of the U, and the reading is then taken on the other leg. Direct readings are possible to hundredths of an inch, and interpolations to thousandths are readily made.

The gauge described reads drafts as high as $1\frac{3}{4}$ inches, and can be made of any desired length. I have found that it is often desirable to read the draft simultaneously at a number of different points in the passage of the gases. By simply hanging the gauge on end instead of horizontally, it can be used to measure air pressures from blowers as high as 17 inches of water.

No single feature of this gauge is original, but I have never

seen so many desirable points combined in a single instrument before. The gauge is rather expensive, of course, when built one at a time, and I have only made them thus far for my own use.

The Eames draft gauge described by Mr. Webber, page 123, embodies some of the same principles, but will give erroneous readings unless a correction is made for the rise in water level in the vertical chamber. I would like to ask how this correction is made?

In answer to Mr. Webber's inquiry regarding thermometers for flue gases will say I have used very satisfactorily an instrument made by Queen & Co., Philadelphia, which reads to 1,000 degrees Fahr.; and has nitrogen under pressure in the tube above the mercury. It can be read without removing it from the flue, but, of course, it is necessary to climb to a point within a few feet of the flue to do so. Another excellent thermometer of the same type is made by the Hohmann & Maurer Co., of Rochester, N. Y.

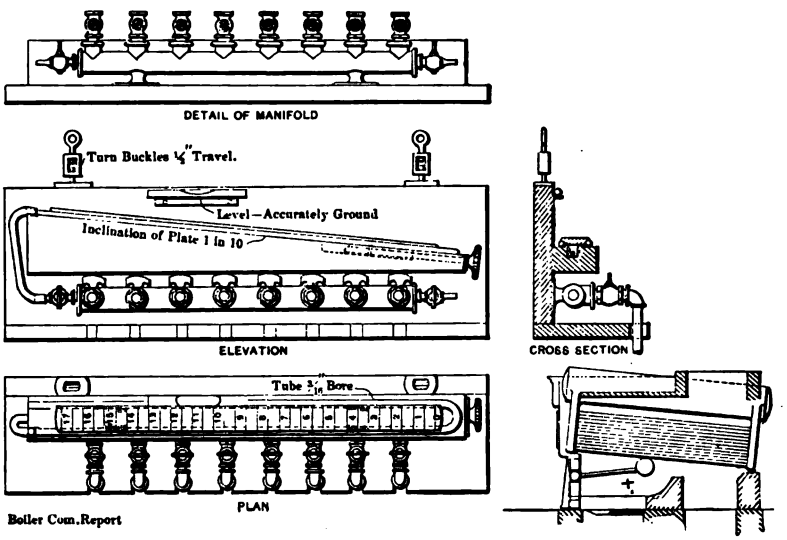


FIG. 11.

The President.—These are all of the written discussions of this paper. Is there any other discussion? Mr. Kent, have you anything further to say in regard to the report?

Mr. Kent—In regard to this inclined-tube draft gauge, I

would say that I invented it three years ago. I do not know when Mr. Bryan invented it. I used it then, and I was greatly disappointed with it. The thing seemed to have a variable capillary attraction. It would vary every hour in the day; the meniscus seemed to change its place with regard to the meniscus at atmospheric pressure, on account of some oily condition that made the attraction between the water and the glass different at different hours of the day. I would like to ask Mr. Bryan what liquid he uses—whether he uses water?

Mr. Bryan.—Yes, sir; but it is a very simple matter to moisten both legs of the tube before you take a reading, and when you do that, your records will be constant.

Mr. Kent.—It may be all right if you know how to use it. I did not. It appeared that the two legs would not at all times moisten equally so as to have the same capillary attraction.

In regard to Colonel Meier's suggestion, I think the suggestion to use the abbreviation "U. E." a good one, and I think in the revision of the report we will say something about it and recommend its use by engineers, and with one definition in every blank so that everyone can find what it means.

In regard to the allowance for draft, he speaks about the unfortunate boiler manufacturer that has to get along with too little draft. The trouble with the unfortunate boiler manufacturer is that he puts in too little grate surface. If he would put in larger grates, he would get along with half-inch or quarter-inch draft. I had an experiment once right in his own city of St. Louis, with Illinois coal, with a water-tube boiler, and I found that the more draft I got the worse I was off. The boiler was guaranteed to give a certain capacity, and under the normal conditions I could not get the capacity. To see what increased draft would do, I put a steam jet in the chimney. That increased the draft up to three-quarters of an inch or more, and I got a great deal less capacity with the increased draft. In fact, I had to pull the coal off the grate surface and start over again. The reason was that this increased draft caused increased rate of combustion. Increased rate of combustion caused higher temperature. Higher temperature melted the ash into clinker, and the clinker spread over the grate and stopped the air supply altogether. It was necessary in that case to clean the grate so as to get rid of the clinker. Of course there would have been less trouble if shaking grates had been used, but the

"unfortunate boiler manufacturer" had not foreseen the need for them.

Mr. H. H. Suplee.—In regard to the variable capillary action spoken of by Mr. Kent, I think an analogy may be found in the capillary correction in a barometer. The height of the meniscus varies according as the column is ascending or descending, because of the friction of the liquid against the walls of the tube. In the case of the siphon barometer, it was originally supposed that, as the two legs were of equal bore, the capillary depression would be alike in both, and so be neutralized; but it was found that a correction was necessary, as one column was descending while the other was ascending. The only way to avoid a variable capillary depression or elevation is to have the bore of the tube so large that the level can be read from the flat surface, so that there is at no time a meniscus of sufficient height to disturb the reading. This fact might be used to correct the difficulty in these draft gauges also.

Mr. David P. Jones.—Referring to the remarks of Mr. Kent in reference to the Eames draft gauge, and gauges of similar construction, my experience exactly coincides with what he says.

I have had such draft gauges in operation during prolonged boiler tests, and have never found them reliable when compared with the standard water draft gauges. I generally found that for the first two or three hours they would give correct readings; after that the variations from the true readings were most marked. Further tests showed still greater or lesser variations from the standard. These variations were not uniform. I finally had to discard them in my practice.

No doubt they could have been adjusted to give correct readings for another period of two or three hours. Indeed, I did so adjust them, but there is not much time to spare for the constant re-adjustment of faulty instruments when conducting boiler tests.

In regard to the suggestion of Mr. Bryan, as to what he calls a manifold for ascertaining air pressures at different parts of a boiler in operation, it is certainly a most excellent thing. It is an appliance that I have used in my practice for some three years, only I call it the central station. I connect one of the nipples of this manifold, or central station, to the draft gauge. The other nipples are connected to little gas-cocks and rubber

tubing leading to any part of the boiler from which it is desired to know the draft, the furnace, the by-passes or the side doors. It is very handy, and saves an immense amount of labor in securing the required data. Except it is necessary to make permanent connections, I generally employ rubber tubing between the central station and the points of attachment. It is much handier and less troublesome to carry about.

In regard to the suggestion of Colonel Meier, of $\frac{6}{10}$ inch of draft, I am heartily in accord with him. With a draft less than that amount when burning Western coals, it is difficult to secure good results.

The suggestion in the code that "the available draft at the damper," is not specific. It should state definitely whether above or below the damper. It is very material to know what the draft is just above the damper, and I think that is the point at which the draft suggested by the Committee should be read. Of course it is generally understood where the draft should be read, but I think it would be better and more specific to fix the place for reading, and state whether above or below the damper.

Mr. Geo. H. Barrus.—I do not agree with the gentlemen who desire to specify a draft of .6 of an inch instead of .5 of an inch, as recommended by the Committee in determining the capacity of the boiler. It would be unjust to many steam-users, not only in the Eastern States, but in the Western States, to require them to furnish a draft of .6 of an inch in order that the boiler should develop the excess capacity required. A boiler which is in reality overrated, might be shown to meet the requirements of capacity laid down by the code if furnished with a draft of .6 of an inch, whereas it would be incapable of doing so with a less draft. The fact is that .5 of an inch draft at the boiler is ordinarily considered a pretty fair draft, and one which few builders or purchasers find insufficient. To secure a greater draft, especially where there are a number of boilers in the plant, requires a chimney having a height considerably more than is provided in plants which meet all the demands of ordinary good construction; and certainly it is very desirable that a boiler should develop the one-third excess power with an ordinarily good chimney. Cases like those mentioned in the discussion where .5 of an inch draft is insufficient should be met as provided for in the recommendations of the Committee, which use the expression "unless otherwise understood," that is, by hav-

ing an understanding between the two parties in reference to the amount of draft desired. I think we should make the recommendations of the report applicable as widely as possible to the normal conditions of good practice, and not to abnormal conditions.

The Secretary.—It has been suggested that the motion to be presented to the Society at this meeting, to record the action of the Society upon the work of its committee should be carefully drawn with respect to the precedents in such matters which have been established by earlier action.

It will be remembered that considerable discussion ensued at the meeting in May, 1886, upon the policy to be inaugurated when the first code was proposed.* The policy then adopted has been adhered to ever since with respect to the reports of expert committees, that the Society as a body does not *adopt* any standards. It accepts the report of a capable committee, discusses it with a view to amending it, and finally orders it printed, with a recommendation at most that the members make use of the work of the committee in their professional work. In this view, therefore, I present the following resolutions:

Resolved, That the Society accept the Report of its Committee on a Revision of the 1885 Code for Conducting Boiler Trials, with its thanks to the Committee for the faithful and continued labors upon the subject referred to them.

Resolved, That the Report and its recommendations as to a Revised Code be printed in the *Transactions*, and the use of the Standard Method of 1899 be recommended to the members of the Society.

Resolved, That upon the completion of the final detail of its work after this meeting, the Committee be discharged.

---

* See *Transactions*, vol. vi., p. 877, Appendix to Proceedings of the XIth, or Atlantic City, Meeting.

No. 829.*

ENGINEERING IN THE UNITED STATES NAVY.

ITS PERSONNEL AND MATÉRIEL.

BY GEO. W. MELVILLE, WASHINGTON, D. C.

(President's Address, 1899.)

IN our Society, the President has the widest latitude in the choice of a subject for his annual address, and, indeed, there is scarcely an established custom as to its nature; but it always seems logical for him to choose a theme connected with the work to which his life has been devoted, and in which he is an expert. This would make my subject "Naval Engineering," and there are several reasons why it is particularly appropriate at this time. Although one other naval engineer has been president of the Society, his address had a different theme, and consequently the subject, at least as a presidential address, will be new. Moreover, this year marks a very decided change in the personnel of engineering in our navy, so that it is particularly appropriate that one of the engineers of the old school should, at the close of this chapter in the history of naval engineering, give a brief review of some of its more important facts with respect to both personnel and matériel.

Every American is naturally proud of the fact that the first successful steam vessel was the work of an American engineer; but it is not so generally known that the first steam war vessel of any navy was designed by the same American (Robert Fulton) and was built in this very city in 1814. Had the war with England lasted a little longer there can be no doubt that the Demologos would have created a revolution in naval architecture; but the close of the war before she was completed rendered her active service unnecessary, and she was finally destroyed by an explosion of her magazine in 1829. The advent of the Demologos did not create an Engineer Corps, nor bring any engineers into the

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

navy, so that the real beginning of naval engineering was when the steamer Fulton was built, and in 1836 Mr. Charles H. Haswell, the Nestor of engineering in this country, became the first chief engineer in our navy. The Fulton was a small vessel of only 1,200 tons displacement, or about what would now be considered a small gunboat; but she was the beginning of what has brought about as great a change in navies as the invention of gunpowder did in warfare.

It is really wonderful to think that the man who was the first chief engineer of this first steam war vessel of our navy is still alive, in full possession of his faculties, and in the active practice of his profession to-day. One of his contemporaries some years since said that the Engineer Corps might consider itself very fortunate in having had for its founder such a man as Mr. Haswell, an educated gentleman and a thoroughly competent engineer. From the very first his every effort was devoted to increasing the efficiency both of the machinery and of the officers who were to care for it, and it is not going too far to say that he has left a lasting impression by his labors, the organization and scheme of examinations having long remained as he made them.

It is a little hard for the young engineers of to-day, whose training, while it may seem to them beset with difficulties in the way of intricate formulæ and abstruse calculations, is nevertheless complete, and makes them masters of an immense amount of accumulated information, to realize the difficulties under which the older engineers, even of the writer's generation, and much more so of Mr. Haswell's, labored. Mr. Haswell himself was one of the first to provide a reliable book of reference for the young engineer, where the results of experience were systematically arranged; but for Mr. Haswell himself there was nothing of this sort, and he had to create the precedents. When we look at the matter in this light, we are filled with admiration for Mr. Haswell and the men of his generation at their excellent solution of the problems which confronted them.

Without going into a detailed sketch of the work done by Mr. Haswell, it may not be amiss to recall to your minds a famous old ship, the machinery for which was designed by Mr. Haswell, who, indeed, made all the drawings for it himself. This vessel was the Powhatan, which for many years was one of the finest of our old ships and rendered most efficient service. Probably every member of this Society living near our eastern coast has seen this fine

old ship. She was built in 1847, and remained in active service for forty years, a monument to those who had designed and built her.

In those early days the average deck officer of the navy did not look upon the steam engine as a desirable addition to a ship, but simply as a necessary adjunct which had to be endured. There were, of course, notable exceptions, and Captain Matthew C. Perry, the first commander of the Fulton, was a liberal-minded man to whom engineers owe a great deal. Yet, even he hardly rose to the point of considering that engineers were a vital part of the ship's complement, and as such should be made to feel that they were as much officers as any others, and their men were just as truly sailors. Neither Mr. Haswell, nor any of his assistants, were regarded, when first appointed, as permanently in the navy, and the assistant engineers were removable summarily by the commandant of the station. Some years ago Passed Assistant Engineer Bennett, writing for one of the reviews, in speaking of this circumstance, expressed surprise that the deck officers should not have realized the mighty force which steam brought to them and should not have embraced every opportunity to take advantage of it. It seemed, on the contrary, to belong to a different world from that in which they had been trained, and instead of endeavoring to become expert engineers, they regarded the machinery and all connected with it as a disagreeable necessity and left its development to the separate Corps of Engineers.

Among the older engineers were many men well known to all mechanical engineers in the country, who in a quiet way did very valuable work. Time will not permit, however, of mentioning them individually in such a survey as we are making.

Some years before our civil war another great marine engineer began to attract attention—Benjamin F. Isherwood. He entered the navy in 1844, so that he is really a contemporary of Mr. Haswell. It is perhaps not exaggerating to say that he is the most brilliant marine engineer whom this country has seen, and his work has made his name known among marine engineers in all parts of the world. His fame will probably rest mainly on his record as an experimentalist, in which field there are few who have ever exceeded him, either in the amount or the excellence of the work done.

The most notable of his experiments was the series which gave the complete demonstration of the relation between cylinder con-

densation and the rate of expansion. Until these experiments, most engineers believed that the law of Mariotte, that the product of pressure and volume is constant, was strictly applicable to steam as well as to permanent gases, and that a very large ratio of expansion with low pressures of steam would be profitable. Isherwood's experiments on the Michigan demonstrated conclusively that under the conditions there obtaining, of a slow-moving engine and a low steam pressure, a ratio of expansion was soon reached beyond which any increase would cause an absolute diminution of economy, instead of an increase thereof, as would have been predicted from a strict adherence to Mariotte's law. Every young engineer knows this thoroughly to-day, and is cautioned about it in his text-books; but so far from its being readily accepted when Isherwood's experiments had demonstrated the true facts, many will remember that he was assailed in the public prints as being guilty either of hopeless ignorance or wilful waste of the government money.

Mr. Isherwood was not only a splendid experimentalist, but a designer of the first rank, and an executive engineer who has not been surpassed. He was Engineer-in-Chief of the navy during the whole of the War of the Rebellion, and during that time was responsible for a large number of designs. Here again he was criticised from the academic point of view, and yet the very faults for which he is criticised only appear, on proper analysis, the more praiseworthy as excellent details of sound designing. He was accused of building engines which were inordinately heavy, which accusation he has never denied. To the mere office engineer this was true, but he realized what they did not, that these engines had to go into the hands of men who were largely untrained and unfamiliar with machinery. The ordinary formulæ for design assume reasonably decent handling, and do not provide for the stresses due to ignorance and carelessness. Isherwood knew that the point of first importance was to build engines which would not break down, and, in fact, could not be injured by ignorant and careless handling. The result of this policy was engines very much heavier than would ordinarily be built; but they did not break down, and they carried our ships to victory. To my mind this was the highest proof of his talent as a sound designer. He had the courage to invite criticism from the book engineer in order that he might insure success for the country.

You all know the story of the Alabama, and how she and her

sister commerce destroyers drove our merchant marine off the ocean. The Navy Department felt it important to get a class of vessels which would be faster than the Alabama, or any other vessel likely to be built, so that they could sweep the seas of all these commerce destroyers. A number of designers were concerned in projecting both hulls and engines to accomplish this result, but although the great Ericsson was one of his rivals, Isherwood's ships were the only ones which really accomplished what was intended. The Wampanoag was the first of Isherwood's ships to be tried, and she was a magnificent success in every way—really in many ways the greatest success as a steam war vessel that the world has ever known, because she distanced everything that had preceded her so much more than has ever been accomplished before or since. The Wampanoag was given a trial lasting 37½ consecutive hours between Sandy Hook and Cape Hatteras, and for the whole run averaged nearly 17 knots per hour. During several 6-hour periods her speed was over 17 knots, and for several single hours she made over 17½. It should be noted also that this was not a smooth weather run, as the trial was ended prematurely owing to a gale, and for some time previous the weather was heavy. The speed made by the Wampanoag was at least 4 knots more than that of any other ship—either mercantile or naval—of her period, and, in fact, it remained the record speed for many years. Even the first fast cruisers of modern navies, like the Esmeralda and Naniwa, while nominally credited with a higher speed, only made it over the measured mile, or for a short spurt, while the Wampanoag's record was, as stated, for more than 37 hours. Another of the Isherwood ships, the Ammonoosuc, was given only a short trial, but showed qualities equal to those of the Wampanoag. The best of the rival ships made a speed of about 15 knots for less than an hour, and the other vessels fell below the Wampanoag even more than this.

It is not perhaps generally known that in calling the Wampanoag an "Isherwood" ship the designation is more inclusive than might be supposed at first glance, for Mr. Isherwood was responsible for those features of the hull design which affect speed. The design of the hull as a whole was worked out by Naval Constructor Delano, an accomplished naval architect, but he simply took the form of hull as designed by Mr. Isherwood and worked out the structural details necessary to carry out his ideas.

It would be supposed that Isherwood's brilliant achievements would have brought him only gratitude and thanks; but, on the contrary, his vigorous methods had aroused a great many enemies, so that at the end of his second term as Chief of the Bureau of Steam Engineering there was sufficient influence to prevent his reappointment to the office which he had so well filled, and he was banished to the Mare Island Navy Yard; but this only gave him an opportunity for some of his best experimental work, and the famous propeller experiments, which are still a mine of valuable information for designers, were conducted there with the assistance of Mr. William R. Eckart, a former engineer of the navy and an honored member of this Society.

After these experiments, and until his retirement, Mr. Isherwood conducted many others which have given valuable information to engineers, and it may be well in passing to remark that his reports of experiments are models to which all young engineers can refer with great profit to themselves. The thoroughness with which the apparatus under experiment is described and its dimensions given, the elegance and lucidity of the language, and the admirable arrangement, are all models of what such a report should be, just as Macaulay's style is so justly commended to all young writers.

From a remark which has just been made as to the qualifications of many of the engineers who came into the navy during the War of the Rebellion, it might perhaps be inferred that there were few men of real ability; but this would be unwarranted, and would be an entire mistake. The total number of engineers was so large that it was utterly impossible to have even a majority of them skilled men; but a number of talented young engineers came into the service, and the profession generally has learned to recognize their ability from the fact that in the years since the close of the war a large proportion of the leaders in mechanical engineering in our country are men who were naval engineers during the war. The first president of this Society (Dr. Thurston), as well as the second (Dr. Leavitt), were naval engineers, and so was that other able man, Charles E. Emery, now gone to his long rest. William Everett, who became famous in connection with the laying of the first Atlantic cable, was another, and so was George Westinghouse, whose wonderful achievements, both as an inventor and as the creator of great industrial works, entitle him to be called the Napoleon of industrial engineering. Theodore Cooper, the

great bridge engineer, and Lay, the inventor of the automobile torpedo, were naval engineers during the war. We must also call attention in passing to Chief Engineers Alban C. Stimers and Isaac Newton, who brought the original Monitor down to Hampton Roads and enabled her to whip the Merrimac. But for their ability and indefatigable labors the results would have been very different. We might also recite case after case of gallantry and daring where vessels were saved by the skill of the engineers; where they lost their lives through attention to duty, or where they distinguished themselves specially in other ways, but time will not permit us to dwell upon these features.

During all the period which we have thus far considered, the engineers for the navy had obtained their education outside of naval influence; but in 1866 a class of young men was ordered to the Naval Academy to be trained as engineers in a naval atmosphere. A number of these gentlemen are still in the service, and were chief engineers of our large vessels during the recent war with Spain. In 1871 engineer cadets were appointed for the Naval Academy, the course being for two years only, until in 1874 a class was appointed whose course was to be for four years.

These young men were appointed by competitive examination open to the whole country, and as the course became better known the numbers who came to compete increased, and their attainments became so high that an unusually able class of young men was obtained as cadet engineers. Unfortunately for the service, Congress was seized with one of its periodical fits of retrenchment, and as no patronage was affected by abolishing the cadet engineer system, the separate course for engineers was wiped out in 1882, and for a time engineering education dropped out of the curriculum at the Naval Academy.

It is probably safe to say that the young men graduated from the Naval Academy under the cadet engineer system presented a higher average ability than any equal number of young men from any of our great technical schools; indeed, so great was their ability that the service was unable to retain them, but the country has profited from the training they received by their work in civil life. A number are filling positions as professors of mechanical engineering in our leading colleges; a number are consulting engineers of the highest rank, and several are engaged in the management of our large manufacturing enterprises—one

(who is a vice-president of this Society) being the general manager of one of the largest electric companies in the world. It is a peculiar pleasure to me to bear tribute to the talents of these young men, because a great many of them have served as my assistants in the Bureau of Steam Engineering, and while I am naturally filled with regret that the navy should lose their services, I also feel proud that my own judgment in estimating their ability should be so thoroughly confirmed by the esteem in which they are held by engineers outside of the navy. I would not have it supposed from my remarks about those who have left the service that they took all the ability with them. Some of the most useful and accomplished officers, graduates and non-graduates, are still in the service, which I trust will be able to retain them.

In this connection, too, it is only right that I should bear testimony to the worth of the men who, at the Naval Academy, trained these young engineers. One of the earliest of the instructors was Dr. Thurston, the first president of this Society, whose fame as an educator is world wide; but there were others who, while not so well known, nevertheless did splendid work. Just as I remarked at an earlier point about the work of Mr. Haswell and others as pioneers, so it was with these early instructors in engineering at the Naval Academy, who had practically no text-books, and who were compelled, in the professional part of the instruction, to depend almost entirely on their own experience; further than this, they had nothing to guide them in the way of a curriculum, and they were compelled to establish one tentatively and develop it as experience dictated.

Curiously enough, just about the time when Congress was undoing the splendid engineering work at the Naval Academy, the Navy Department itself was formulating plans for vessels which should be designed along lines so different from those which had preceded that the familiar epithet applied to them—the "new navy"—is entirely appropriate. The labors of the first advisory board made available a mass of information, as a result of which Congress in 1883 authorized the building of the four Roach cruisers, which were the beginning of the new navy. These vessels, I may say in passing, although possessing few features of novelty, as far as marine engineering in general is concerned, were nevertheless a marked change from the old wooden ships which had preceded them, and they rendered very

valuable service, and are still, with modernized machinery, very satisfactory and useful vessels.

In 1885, when Mr. Whitney became Secretary of the Navy, there was inaugurated a period of great activity and progress in the Navy Department, taking what had been done by Secretary Chandler, who started the new navy, and carrying on the work along the lines of logical development. Mr. Whitney's determination was to have ships which should be fully the equals of those in any country, and it was through him that the speaker was called to the position of Engineer-in-Chief of the navy in 1887, succeeding his life-long friend, Commodore Loring, one of our past presidents, whose reputation as an engineer is too well known to all of you to need any praise from me.

I desire, in this connection, to say that no head of an office has ever been more fortunate in the young men who have been his assistants. No one has ever had the coöperation of abler men, and this has always been rendered with a loyalty and cordiality which deserve all the praise I can give, and I say with perfect frankness that if the progress of naval engineering in our country has been great during the past twelve years, it is due, in a large measure, to the cordial assistance of the talented young men who have worked with me.

It is generally admitted that the machinery of our navy has been in all respects fully abreast of the latest developments, and in many respects we have taken the lead. One of the first things which may be mentioned is the fact that during the period before water-tube boilers were used in any navy, and when in some foreign navies there was a great deal of trouble with the shell boilers, due to the effort to get an abnormally large amount of work out of them, we had no such trouble. We believed in the principle of never sending a boy to do a man's work, and as a result we never had a boiler incapacitated through leaky tubes, and never lost a trial trip on this account, while failures of this sort were very common things abroad.

One of the first things we did was to establish the use of water-tube boilers and light compound engines for our steam launches. Private builders in this country had used water-tube boilers, but the results, owing to the type of boiler employed, were not altogether fortunate. We found a boiler which has proved entirely satisfactory, and developed light machinery which was also sufficiently substantial to stand the comparatively rough handling

with which the machinery of small boats must inevitably meet. We are to-day the only navy which uses water-tube boilers exclusively in its small boats. When we started, the effort was made to save as much water as possible, and small blowers run at a high speed were used for draught, but the inevitable hum caused so many objections to be entered by officers of high rank that we were driven to the use of the steam jet. It was, of course, important that the most economical form of jet should be used, but when we came to determine this question we found that there were absolutely no reliable data in existence. As a result, we carried out a valuable series of experiments at the New York Navy Yard, and found an exceedingly simple form of jet, which was also very economical, giving us a fairly high rate of combustion for a comparatively small expenditure of steam.

It was evident to us that with the prevailing tendency toward continual increase of speed and power, with the accompanying increase of steam pressure, the shell boiler would at some near date have to be superseded by the much lighter water-tube boiler, and we therefore invited a competition among the various manufacturers of water-tube boilers, with a view to determining the one which, all things considered, would be best adapted to naval uses. Although this competition occurred about ten years ago, you are doubtless familiar with the circumstances, and that, as a result, we installed about 5,000 horse-power of Ward boilers in the coast defence vessel Monterey, this being at the time, and for several years, the largest installation of water-tube boilers in any naval vessel. I am glad to say that these boilers have always given satisfaction and are still in use. At this same time water-tube boilers of a different type were installed on one of our torpedo boats, and we have never used any other than water-tube boilers on any of the numerous torpedo vessels which have been built since.

It would have been an easy matter, and it would have brought temporary praise to the Engineer-in-Chief, if, after the successful trial of the Monterey, we had at once launched out into the use of water-tube boilers for all our vessels; but we felt that there had not been sufficient experience in their use to warrant us in making such an experiment in our first sea-going armorclads, and consequently, for a number of years, and even after foreign navies had begun to use water-tube boilers extensively, we continued to use the shell boilers in our large vessels. Two years ago, when I felt that there had been sufficient experience to warrant us in the

final adoption of water-tube boilers, I recommended in my annual report to the Secretary of the Navy that we should definitely adopt water-tube boilers for all classes of vessels. For reasons altogether apart from the machinery, we were not at first successful in securing water-tube boilers in the department's own designs in spite of my urgent recommendation, but the firms which tendered on the government's designs also offered to guarantee higher speeds if they were allowed to use water-tube boilers and more powerful machinery in hulls of their own design. This I had advocated very strongly, and both the technical and daily press of the country had supported this position very heartily, believing that it would be a woful mistake for our country to build sixteen-knot battleships when the rest of the world were building such to make eighteen knots, and when by the use of water-tube boilers we could so readily do it. I am glad to say that the department accepted the builders' offer, thus definitely adopting water-tube boilers and securing the eighteen-knot battleships for which I had worked so hard. At the present time all our new designs include water-tube boilers exclusively.

One of the notable improvements in design which we introduced for large vessels was the use of triple instead of twin screws. We were not the originators of this method, as small vessels in both France and Italy had demonstrated its success, and both France and Germany were building vessels of about 12,000 horse-power with this system of propulsion. When it came to the design of the Columbia, the first of our commerce destroyers, with 21,000 horse-power, I was satisfied, after careful study of the problem, that we would need to use triple screws to attain success. At the beginning I did not anticipate an economy in propulsion, and the adoption of triple screws was for structural reasons; but when the Columbia's trial occurred we found that there was a material increase in the propulsive efficiency. When the Minneapolis was tried shortly afterward with the same system of machinery, this fact of greater economy was again established, so that we now feel that triple screws are justified not only for numerous other reasons, but on the ground of economy. This arrangement of propellers has become very popular in a number of foreign navies which have followed it out on a considerable scale, and have built all their large vessels with triple screws. It is probable that we shall do the same thing in our larger ships of the new programme.

During our late war with Spain we developed and utilized two engineering schemes which had never previously been tried in actual service—a repair ship and a distilling ship. The former is one phase of the modern method of treating large work by taking the tool to the work instead of bringing the work to the tool. The Vulcan was the equal of anything except a very large repair yard, and after the battle of Santiago she was almost invaluable in the much needed general overhaul of all the ships. Besides an admirable outfit of machine tools and engineering stores, the Vulcan was specially notable for using the first cupola ever installed on board ship. The distilling ship was fitted with a four-unit, triple-effect distilling apparatus capable of furnishing, after use for some time, 50,000 gallons of fresh water per diem with an economy of over twenty pounds of water per pound of coal burned under the boilers. With clean coils the Iris actually furnished over 100,000 gallons per diem. The bunker capacity is 3,000 tons of coal, thus giving a potential capacity of distilled water of 60,000 tons, or as much as twelve of the largest tank steamers. The advantages of a distilling ship over a "tanker" are very numerous and obvious.

The war with Spain was too short to give a chance for great experience in any line, but the work of the Oregon stands out as a brilliant illustration of the fact that the modern battleship is not only the creature of the engineer, but is absolutely dependent upon him for success. You all know the story of Milligan's work as the chief engineer of the Oregon: of his ceaseless vigilance to keep everything in order and prevent any deterioration; of how he saved the good coal for the day of battle which finally came (though he was told it never could come), and, above all, how he persuaded Clark, the commanding officer, to have *all* the boilers ready all the time, although others had steam on only half the boilers and, where it could be done, half the engine power was laid off. I am firmly convinced that the brilliancy of the victory at Santiago is largely due to Milligan's skill and foresight, and, as I said, this case is direct proof that however admirable as a great fighting machine, the battleship is useless except in the hands of trained engineers.

During the last fifteen years naval engineering has shared in the general progress of all marine engineering, and has led in many respects. Wrought iron, which was formerly the mainstay of the designer, has practically disappeared, to be succeeded by mild steel, which is not only stronger but much more reliable, and the

manufacture and inspection of which has been brought almost to perfection. There is little doubt that the great improvements which have been made in both engines and boilers would have been impossible but for the greatly improved material. One of the greatest improvements has been in the reduction of weight of machinery, and this has been due both to improved material and to radical changes in design.

In the engine there has been a better disposition of the material; and the use of hollow instead of solid shafting and other large pieces of forged material, the use of steel castings, etc., have been instrumental in enabling the use of higher pressures, and particularly of higher rotative speeds. These rotative speeds have become possible since we have learned to design the propellers on rational principles. In the old days, as you are well aware, the rule was to make a propeller as large as possible, consistent with immersion, and this, on account of the empirical rules for the ratio of pitch to diameter, necessarily kept down engine speeds. Now we know that within reasonable limits we can design a propeller to suit almost any engine speed; consequently, we are left free to adopt as high a rotative speed as is desirable and consistent with safety, assured that we can afterward design an economical propeller to fit it.

In the boilers, the reduction of weight has been due, apart from the more recent adoption of the water-tube type, to improved material, and especially to forced draught. This, as you are doubtless aware, is an American invention almost contemporaneous with Fulton's early steamers; but it had almost disappeared, and after a brief revival under Isherwood during the civil war, had again died out until it was taken up in some of the foreign navies. At the present time no naval machinery is ever designed without the use of forced draught.

Pressures have been gradually rising, and even with shell boilers as high a pressure as 200 pounds has been employed; but with the present plans of using 250 pounds at the engine, with either triple or quadruple expansion, and some 25 or 50 pounds more at the boilers, nothing but the water-tube boiler would do.

At the present time it seems as though we had practically reached the highest development possible with existing types of machinery for naval purposes, leaving the designer room only for greater perfection in details. We do not, of course, believe that finality has actually been reached, and it is possible that some

radical change may take place which will give us a new type of machinery. Some of the more enthusiastic members of the profession think that the steam turbine is to be the successor of the present steam engine, and assuredly the performance of Parsons' Turbinia is sufficiently remarkable to justify the most careful study and further experiment. It is very interesting in this connection to know that in this country the development of the steam turbine is in the hands of one of our famous engineers, who is also one of the honorary members of this Society—Mr. George Westinghouse. He has been developing the steam turbine with special reference to its use in driving electric generators, and some of the results already obtained are very remarkable. With his characteristic energy and courage, he is not satisfied with results on a small scale, but is now getting out a steam turbine to develop about 2,000 horse-power on a single shaft, and when this has been built and thoroughly tested we shall be in a position to appreciate more thoroughly the bearing of this form of prime mover on naval engineering.

At the beginning of this address it was remarked that this was a peculiarly appropriate time for discussing the personnel of naval engineering, on account of the radical change which took place this year in the status of the engineer officers of our navy. For many years, as you all know, there had been an unfortunate controversy in our navy, known as the "line and staff fight," resulting from the fact that the line officers, as the older organization, were unwilling that the staff, and especially the engineers, should have all the rights to which the latter believed themselves, as naval officers, entitled. The great grievance of the engineers was that they held what was called "relative rank" and were denied the command of their men and a military title, so that there was always room for the statement, which unfortunately was made at times, that they were not really officers and had only a *quasi* rank. All men who have passed middle age have probably realized personally the difficulty of bringing about any radical change in existing conditions of long standing, and I really believe that the trouble in the navy was largely a matter of inertia. An enormous amount of valuable effort was wasted on both sides; the one to secure the coveted rights, the other to prevent this result; but matters had been shaping themselves for a considerable time so as to make a new state of affairs inevitable. The change in the means of offence on board ship had brought the line officer to the point of

realizing that he must, of necessity, be a good deal of an engineer, and such work as the manufacture of guns, which is, of course, purely mechanical engineering, showed this very strongly. On the other hand, the work of the naval engineer on board ship, which had originally been to direct a very few men with small machinery, has been gradually changing, until, on some of our large ships, the chief engineer commanded in fact, although not in name, about half the crew; consequently, his duties had become very largely executive and military, and thus of the same nature as the duties of the line officer. As a result of this state of affairs, many of the more liberal minds on both sides believed that the solution of the vexed question in the navy was the consolidation of the line and engineer corps, and making the new line officer an engineer as well as a sea warrior, or, as Congressman Foss expressed it, a "Fighting Engineer."

A board of naval officers, presided over by Colonel Roosevelt, then Assistant Secretary of the Navy, finally formulated a scheme for carrying out this idea of amalgamation, which was actually proposed in the board by a line officer (Captain Evans). When it was submitted to Congress, two members of the House Naval Committee, Hon. George E. Foss and Hon. A. G. Dayton, took up the measure very actively, and with the assistance of other members of the committee, pushed it forward to complete success, until the Personnel Bill became a law March 3, 1899.

Under the provisions of this law the officers of the Engineer Corps were transferred to the line and given new commissions as line officers with *actual* rank, thus effectually disposing of the phantom of *relative* rank. I wish particularly to emphasize the fact that the basis of the law, and the consideration that led to its adoption, was the demonstrated fact that to have a successful navy every line officer must be a thorough engineer. This was very well phrased by Colonel Roosevelt in his report of the findings of the Personnel Board, where he said "every officer on a modern war vessel, whether he wants to or not, must in reality be an engineer." Mr. Foss, in his report to the House recommending the passage of the bill, used language of the same import, and elaborated the matter still further, and in the speeches on the floor of the House this was the subject which had most weight, and which brought about the passage of the measure.

A natural inquiry on your part will be, How successful is this measure in actual practice? To this the answer is that any such

change must, of necessity, require time, and it is too early yet to speak of results. I wish, however, to put on record my opinion that if the administrative details necessary to carry the law into effect are worked out with an honest desire to give due effect to its plain intent, and with a desire to make it a success, the results will be all that can be wished, and we shall have the most efficient navy in the world. If, through any unfortunate combination of circumstances, which, however, I can hardly believe possible, there should be any temporary indifference or opposition on the part of those in authority, the result can only be lack of efficiency and disaster in case of war until the intent of the Personnel Board and Congress is put into working effect.

It may occur to some who have only looked into the matter hastily that this scheme of amalgamation is contrary to the spirit of the age, with its tendency toward specialization; but, as an actual fact, the reverse is true. The misapprehension comes from a failure to consider the case thoroughly. When it is proposed to make every naval officer an engineer, we mean an engineer specially fitted for the work to be done in the navy, just as the other training of the line officer is for the duties which come specially to him; in other words, this new line officer—the "fighting engineer"—is to be a specialist in the very best sense of the term; that is, a man who has been specially and thoroughly trained for the work he has to do.

I think we may all feel a pardonable pride in this change in the status of our naval engineers. The amalgamation is analogous to that which occurred in the British navy just after Cromwell's time, and the analogy is not a fanciful nor forced one, but is strictly accurate. Up to the time of that change, naval vessels were manned by soldiers who did the actual hand-to-hand fighting, but were entirely ignorant of seamanship, and another set of men who managed the propulsive power of the vessel, which was then the wind acting on the sails, and who directed the movements of the vessel. These men had no military rank, and were designated simply by professional titles, being known as "the sailing master and his mates." The amalgamation which then occurred was of the soldier and the sailor, and out of this amalgamation was evolved the man-of-warsman and the naval officer. With the advent of mastless ships, we had reached an analogous condition where one set of people fought the guns and another set managed

the propulsive power, this time steam acting through machinery. The new amalgamation has made a new naval officer, "the fighting engineer," to be followed in time by the successor to the old man-of-warsman, who will be the "fighting mechanic." The basis of the new amalgamation is the fact that in this industrial age engineering and mechanical skill are the source of efficiency in our navy, and this, as I have said, is a pardonable cause of pride to all of us as engineers.

In the past, engineering has been hampered at times in our navy on account of the subordinate position which its representatives held in the naval organization; but in the future, as the whole body of naval officers will be engineers, we have every reason to anticipate an era of progress and efficiency greater than has ever been known in the history of navies.

This address has grown to a length which I hardly anticipated when I began, and for which I ask your indulgence, trusting you will agree with me that the importance of the subject and the opportuneness of the occasion excuse the extent of the address. We of the old school have lived to see our fondest hopes realized in the proper recognition of our beloved profession before we have actually ceased to participate in its active work. We linger with fond memory over our trials and discouragements, as well as our successes, and we may, perhaps, realize that some of our successes have been due to the stimulus of opposition; nevertheless, it does not make for success that when one is honestly doing his best work he should feel that much of it may be in vain on account of senseless opposition and failure on the part of those in high places to appreciate it; and as we older men leave the scene of action and pass on our work to the younger generation, we can congratulate them heartily on starting out under circumstances which are so infinitely better than those of our time, and which give them so much greater opportunity for highly efficient work for the republic.

I thank you very sincerely for your patience in listening to this long address, and also for the kind consideration which you have all shown me during my term of office as President. I wish also to express my gratitude to those who have been office bearers with me for their coöperation, and particularly to our most efficient Secretary, to whom the Society, and every President, owes so much.

No. 830.*

COMPRESSION AND LIQUEFACTION OF GASES.

BY ARTHUR L. RICE, BROOKLYN, N. Y.
(Junior Member of the Society.)

THE first experimentation upon the liquefaction of gases seems to have been suggested by Sir Humphry Davy, although Michael Faraday was the one to do the actual work. It was in 1823 that Davy, then the Director of the Royal Institution, instructed Faraday, his assistant, to heat hydrate of chlorine in a closed tube, not stating what result was expected. This Faraday did, and got a yellowish, oily moisture on the sides of the tube, which he and a friend who was standing by took to be some foreign matter remaining from a previous experiment with the tube. Faraday filed off the end of the tube to cleanse it and was astonished by a violent explosion. He repeated the experiment, and found, by testing, that the oily drops were liquid chlorine. This incident started him on a train of investigation which resulted in the liquefaction of sulphuret of hydrogen, carbon dioxide, nitrous oxide, cyanogen, ammonia, and hydrochloric acid, all during 1823.

A little work had been previously done, as Faraday himself afterwards stated, by Monge and Clouet some time previous to 1800, in liquefying sulphur dioxide, and in 1805 by Northmore who liquefied chlorine and, possibly, sulphurous acid, using the same method as Faraday. The means employed seem ridiculously simple when compared with the results obtained, but the two prime elements, pressure and cold, were both present. In one end of a bent glass tube (see Fig. 12) was placed a mixture of chemicals which, on heating, would give off the desired gas, and the tube was then sealed; enough material was used so that, in the closed tube, a very considerable pressure would be produced by the gas thus set free. The other end of the tube was plunged into a cooling mixture to condense the gas; a capillary tube,

* Presented at the New York meeting (December, 1899), of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

open at one end, containing a drop of mercury, was placed inside the large tube so that the number of compressions of the air might show the number of atmospheres pressure existing. With this apparatus the work of 1823 was done, the pressures being carried as high as 50 atmospheres, or 750 pounds per square inch.

The subject was then dropped for twenty years by Faraday; Colladon, an assistant of Ampere, meanwhile experimenting, but with no result. Colladon's apparatus was, however, with the single addition of a release cock, the one with which Cailletet has since done much excellent work. It consists of a tube (see Fig. 14), at one end open, of large diameter and of thin glass; at the other closed, of small diameter and with heavy walls; the large end of the tube was placed inside a heavy iron chamber and

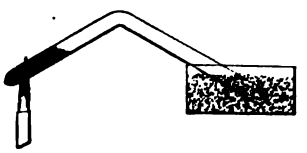


FIG. 12.

FIG. 13.

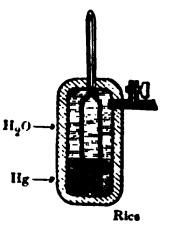


FIG. 14.

a packed joint made around the small part of the tube, in which the gas was placed, and where it was compressed by pumping mercury into the iron chamber. Around the small part of the tube could be placed a cooling bath. Cailletet added an expansion cock by which the pressure could be relieved suddenly and the gas thus further cooled; he also improved the form of the tube.

In 1845, Faraday again took up the experiments upon gases. He used air pumps combined as a two-stage compressor, pumped the gases into glass tubes and inserted them in a cooling mixture. During the twenty years' interval, Thilorier had made liquid carbon dioxide by compression, and then, by evaporation of the liquid, had produced the solid snow; also Natterer had, by the use of a mixture of carbon dioxide snow and ether, and by pumping away the vapors, so that a continuous evaporation was produced, succeeded in freezing mercury, so that means were at hand for producing a much lower temperature than at the time of the earlier experiments. Natterer had

also tried experiments on the compression of gases, going as high as 4,000 atmospheres or 60,000 pounds per square inch on oxygen, but did not cool the gases and therefore get no liquefaction. He did, however, get gases whose density was greater than that of their liquids, as it has since been determined, thus proving the fact, had he but known it, of the existence of a critical temperature of substances. In his experiments of 1845, Faraday used the carbon dioxide-ether mixture of Natterer, and thus was enabled to obtain a temperature of − 106.2 degrees Fahr. (− 76.6 degrees C.), at atmospheric pressure, or, at a vacuum of $\frac{1}{16}$ of an atmosphere, a temperature of − 166 degrees Fahr. (− 110 degrees C.); the bath would only last 15 minutes, so that his observations on the liquefied gases were practically instantaneous. By this means he solidified sulphur dioxide, sulphuret of hydrogen, nitrous oxide, hydriodic and hydrobromic acids, and ammonia. He tried to liquefy hydrogen, oxygen, nitrogen, carbon monoxide, and coal gas, using pressures of from 27 to 50 atmospheres, but failed from not realizing the existence of a critical temperature, and these gases were long known as incondensible.

This point was investigated a little later, in 1849, by Dr. Andrews, who proved, as had Natterer before him, that some gases could not be liquefied by any amount of pressure; but went further and showed that, by cooling, some of them would be condensed, thus determining the existence of a temperature below which, and only below which, a gas may be condensed to a liquid.

For a time after this the work of experimentation went on intermittently in several laboratories, but without notable result, although some improvements in the details of apparatus were made. An important suggestion was made in 1857, by Sir William Siemens, that refrigeration might be produced by expanding a compressed gas, either in a cylinder doing work, or freely, to a lower pressure, and using this cold gas to cool, before expansion, the gas coming to the apparatus. It is on this basis that the latest investigators have proceeded, and it is this means which has accomplished, in the closing years of the century, the long-sought result of the liquefaction of all gases. During this time of apparent inertness, Messrs. Pictet and Cailletet, the one in Switzerland, the other in France, working in ignorance of each other's efforts, were reaching toward the same

goal, but along different lines. Cailletet, using the apparatus of Colladon, modified as previously mentioned, was working as a man of pure science, interested in discovering facts; Pictet wanted to liquefy gases in quantity, so that they might be used for refrigeration or otherwise. The results were announced to the world at about the same time in December, 1877, but Cailletet is proven to have reached his result in the liquefaction of oxygen on December 2d, while Pictet accomplished the same thing on December 22d. Cailletet had the liquid in a glass tube, could study its properties visually, and could liquefy the same gas again and again; but he could not get at it, and had only a minute quantity. Pictet had his liquid in a steel tube so that it could not be seen, and he could not repeat the experiment on the same charge of gas to verify a result, but he had about one and one-half cubic centimeters of the liquid, a considerable amount as such things had gone up to that time. In his original apparatus, Pictet made no provision for drawing off the liquid, but in a later form this was accomplished by means of a pipe, and a cock *outside* the cooling chamber, though no means of preserving the oxygen in its liquid form had then been devised. The greater importance of Pictet's work lies in the apparatus which he devised. This was what is termed the cascade system (see Fig. 15); a circulating pump was used to draw the vapor from a jacket filled with liquid sulphur dioxide; this vapor was forced through a water cooled condenser, and then compressed to liquid form, so that the action was much the same as in a modern refrigerating machine. The sulphur dioxide jacket was used to cool the vapor of carbon dioxide, this, in turn, being used to cool a tube into which oxygen gas was forced under pressure, by heating a large quantity of potassium chlorate in an iron bomb. A cock on the bomb allowed of the escape of part of the gas, thus cooling the remainder by expansion; in this way, with the oxygen tube at −220 degrees Fahr. (−140 degrees C.), and a pressure of 320 atmospheres, Pictet was able to get a tube ⅓ full of oxygen. The temperatures were −85 degrees Fahr. (−65 degrees C.), at 5 atmospheres in the carbon dioxide chamber, and −13 degrees Fahr. (−25 degrees C.), at 2.75 atmospheres in the sulphur dioxide chamber.

Cailletet experimented with various gases, among others laughing gas, acetylene, and carbon monoxide. He also, as did Pictet, got a mist of hydrogen, but was not able to get it in

liquid form; he is credited with being the first to use liquid ethylene as a cooling agent in the liquefaction of gases.

During the next decade, experiments were carried on by two Polish chemists, Wroblewski and Olszewski, who worked in collaboration. They used Cailletet's form of apparatus, and, in the latter part of the work, used Pictet's cascade system for cooling the compression tube. In 1884 they confirmed the results obtained by Cailletet on hydrogen.

In this same year Dewar, at the Royal Institution, showed that liquid air could be produced by the use of solid carbon dioxide and nitrous oxide as cooling agents, giving −184 degrees Fahr. (−120 degrees C.), a compression to 200 atmospheres and subsequent expansion; the amount liquefied was about 5 per

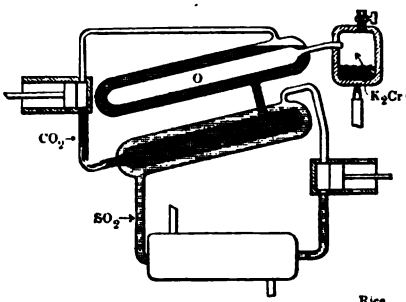


FIG. 15.

cent. of the air compressed. He also devised for holding liquid gases the vacuum flasks which bear his name. By this means the rate of evaporation of a liquid gas is reduced to $\frac{1}{5}$ that in the open air; if the inner wall be coated with mercury to form a heat mirror, the evaporation will be only $\frac{1}{13}$ the free rate. These flasks were the means by which liquid gases were handled and kept in static form, until very recently.

After Wroblewski's death, which occurred in 1888, Olszewski continued the experiments. He replaced the glass tube of Cailletet by one of steel, having a stop-cock by which the liquid could be drawn off, and was thus enabled to get amounts of the gases which could be handled in the Dewar flasks.

Dewar at first used the Cailletet apparatus as altered by Wroblewski, but changed to that of Pictet, using, however, pumps to compress the gases previously made, and force them into the liquefying chamber; he used ethylene in place of car-

bon dioxide, placed the draw-off cock inside the cooling chamber and, later, added the regenerative principle suggested by Siemens for cooling the chamber in the case of hydrogen liquefaction. Professor Dewar is the most extensive of the modern experimenters in the field of the liquefaction of gases; he, first, liquefied oxygen in large quantities and held it in liquid form in 1891, and a little later liquid nitrogen was produced. In 1895 he demonstrated that air in the liquid form could be frozen to a jelly-like solid by the expansion method, the jelly proving to be a mass of nitrogen with the liquid oxygen of the air contained in the interstices; this solid air melts instantly on contact with the atmosphere. In 1896, before the Chemical Society, the production of a jet of liquid hydrogen by means of the expansion of the cooled and compressed gas and the regenerative method of cooling the incoming gas was announced; by the use of this hydrogen jet, oxygen and air were frozen to a solid white mass.

Continuing this line of research, in May, 1898, Dewar was able to collect hydrogen in static condition, and to hold it in this form by the use of the Dewar bulbs at a temperature of −396.4 degrees Fahr. (−238 degrees C.), only 65 Fahrenheit degrees above the absolute zero.

Although liquid air has received considerable attention from the investigators already mentioned, they have been particularly interested in the scientific investigation of the properties of the elementary gases. The workers in this particular field have been Tripler, Linde, and Hampson, all of whom have been aiming at the simplification and cheapening of the production, so that the liquid may be made of use. All three have been working along the lines of a direct regenerative action, as suggested by Siemens. Dewar has also done work along this line, combined with cooling by a separate fluid, but in a smaller way as would be expected in a chemical laboratory. The principle is this: A perfect gas expanding to do work loses heat; if this cooled gas be exhausted so as to jacket the pipe through which the incoming gas enters, it will cool that incoming gas; the process is cumulative without limit, if the machinery is frictionless and insulated against heat from the surrounding objects. Solvay built a machine on this principle, but was unable to get lower than −139 degrees Fahr. (−95 degrees C.), on account of the heat due to the fricton of the pistons and to conduction.

In a perfect gas no lowering of the temperature would result

from lowering of the pressure by free expansion, but none of the so-called gases are perfect, and all are cooled somewhat by expansion through an orifice. Joule and Kelvin found that with air the fall of temperature is about 0.45 degrees Fahr. ($\frac{1}{4}$ degree C.) for each atmosphere difference of pressure at the orifice, at ordinary temperatures, and that the effect increases as the temperature falls, because the gases are coming more nearly to the vaporous state. If, then, air be compressed to a high pressure and allowed to expand through a small orifice, it will become considerably cooled and may be used to cool the incoming air, which, in turn, will lose heat by expansion; the process may be carried on until some of the air, on or before leaving the orifice, is liquefied.

Tripler's English patents of 1891 seem to be the first specification of any definite machinery for thus liquefying air. Linde and Hampson did not come forward with a working apparatus until 1895, and, at that time, Tripler's apparatus was about perfected. The latest (1898) type of Linde's machinery is shown in Fig. 16. The fall of temperature, as previously stated, is proportional to the difference of pressures at the orifice, and this difference should, therefore, be large; the work required to compress the air again will depend upon the ratio of the pressures, *i.e.*, upon the ratio of compression, and should be as small as possible. This necessitates that both pressures be high for the most economical working, hence Linde works his machine between 200 atmospheres and 16 atmospheres for all the air by expanding through the valve *a*; $\frac{1}{5}$ is then expanded to 1 atmosphere through the valve *b* so as to cool it still further, and about $\frac{1}{4}$ of this amount is condensed. The expanded air is sent back in the outer pipes as shown, the part which is at 16 atmospheres to the compression pump, and the rest to the atmosphere. *f* is a separator and *g* a freezing bath, both being used to remove the moisture from the air; *d* is the compression pump, and *e* a pump for supplying at 16 atmospheres as much air as escapes at *b*. In the earlier form of the machine, none of the air was expanded below 50 atmospheres, and the air was cooled by a surface condenser supplied with water. With this apparatus, about .9 of a quart of liquid can be obtained per hour with the use of 3 horse-power, this being about 5 per cent. of the air handled; the first liquid will appear about two hours after starting up the machine.

Hampson's apparatus is somewhat simpler and more compact. Three helices are arranged in the form of concentric cylinders, and connected so that air is forced through them successively beginning at the outside; expansion occurs at the lower end of the inside spiral, and the released air flows back along the outside of the three coils in a reverse direction and escapes to the atmosphere near the inlet. With this device Hampson claims to have condensed about 1.2 quarts of air per

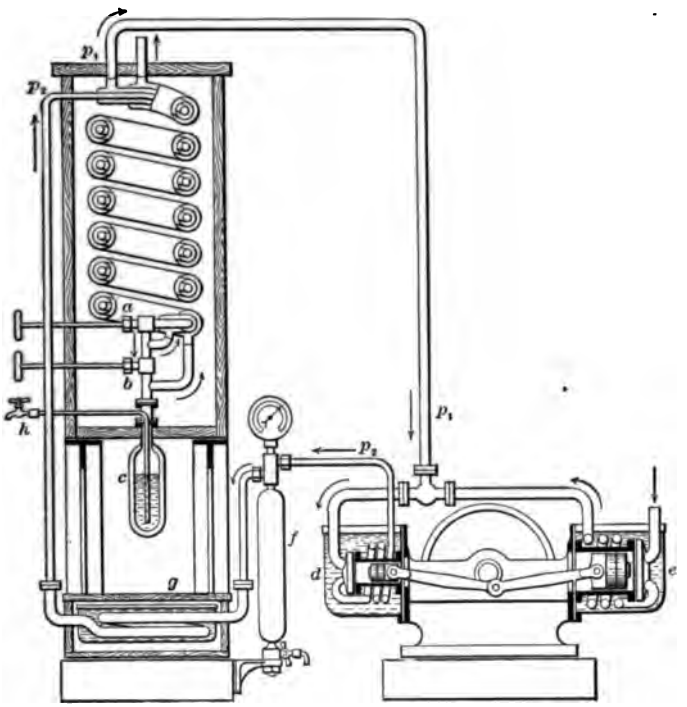


FIG. 16.

hour at an expenditure of 3.5 horse-power, using a pressure of 120 atmospheres expanded to 1, and getting 6.6 per cent. of the air handled as liquid; the liquefaction commences in 15 minutes from the time of starting.

Lennox, an assistant of Dewar, reports the making of 1 quart of liquid per hour by the cascade system with an expenditure of 3 horse-power, and at a pressure of 300 atmospheres expanded to 1. Dewar's latest apparatus is shown in Fig. 17. In this both regenerative action and cooling by carbon dioxide are

employed; if air be drawn from steel cylinders at 200 atmospheres pressure and expanded to 1, the amount of air liquefied will be about 5 per cent. of that used, and the liquid will begin to flow in six minutes from the time of starting.

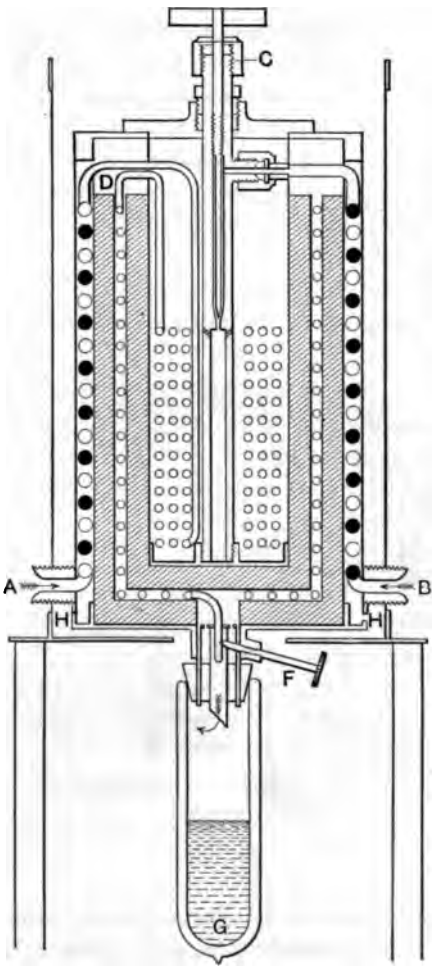


FIG. 17.

These achievements, though notable, seem petty when compared to the work of Mr. Tripler in producing gallons of the liquid, and handling it in ordinary tin cans with only a felt or air packing for protection from heat absorption. Mr. Tripler's apparatus (Fig. 18) consists of a three-stage compressor drawing

air directly from the atmosphere and driven by a steam engine. The air is taken first into the low-pressure cylinder, where it is compressed to 65 pounds per square inch; it is then sent through an intercooler to reduce the temperature to that of the atmosphere, and taken into the intermediate-pressure cylinder; from that, at a pressure of 400 pounds, it is taken through a second intercooler to the high-pressure cylinder, where it is forced up to 2,000 to 2,500 pounds, and thence sent to the aftercooler to be reduced again to the temperature of the atmosphere. The air is passed through a sepa-

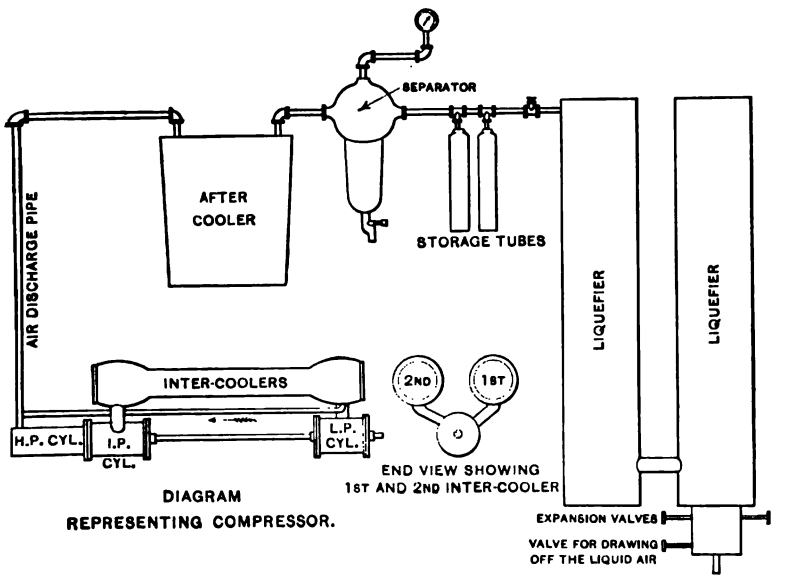


FIG. 18.

rator to take out all moisture and then passes to storage tubes in which compressed air, not in the liquid form, may be kept. The liquefier is Mr. Tripler's special invention; this takes the air from the separator and, by expansion through a coil of pipe and a small orifice, cools it to a low temperature; it passes up around the coil of pipe, cooling the air inside and thus giving the regenerative action. The expansion valve is placed at a little distance above the bottom of the coil, so that some liquid air collects in the bottom of the coil, and thus serves to further cool the air as it comes to the expansion cock. The air which is to be drawn off col-

lects in the liquefier just below the expansion valve, and may be drawn off at will. The expanded air escapes to the atmosphere after having been used to cool the coil of the liquefier. The capacity of the present plant is two to four gallons per hour, and the air will begin to liquefy in 15 minutes after starting up. No data are available as to the power used in the compression.

The physical constants which have been determined with regard to the liquefied gases are given in the following table, which was prepared by Mr. Walter Dickerson. It will be noted that the order of the liquefaction of the gases historically is almost exactly that of the descending critical temperatures; it is the attaining of a low temperature limit that has taken all the time and study that have been devoted to this matter. Some of the gases when in the liquid form are lighter, and some heavier than water, as shown by the values of specific gravity; of the constituents of air, nitrogen is lighter and oxygen is heavier; the mixture, containing $\frac{4}{5}$ nitrogen and $\frac{1}{5}$ oxygen, is a little lighter than water.

Professor Jacobus and Mr. Dickerson have found the latent heat of air at atmospheric pressure to be about 140 British thermal units, but this figure is stated as only a rough approximation. This is about the only value which has been determined with regard to air in the intermediate or vaporous state.

Any calculations as to the efficiency of liquid air as a fluid for a prime mover must necessarily be only approximate. The approximations can, however, be made on the right side, and the air given the benefit of the doubt.

Professor Henry Morton has recently made some calculations regarding the maximum amount of power which could be obtained by the expansion of one pound of liquid air under certain circumstances. The same hypothesis which he used will be assumed and his figures adopted.

Suppose one pound of liquid air to be confined in a cylinder and heated to 70 degrees Fahr., then let it expand at 70 degrees to atmospheric pressure, the expansion to be hyperbolic. It is not known what the volume of the air will be at 70 degrees before expanding, but it is certain that its ratio of expansion will be less than it would be if expanding from the volume of the liquid at -312 degrees to the volume of the gas at 70 degrees and atmospheric pressure; this ratio is something less than

TABLE I.

Number of Line.	Substance.	Physical Constants.										
		Symbol.	Critical Temperatures.		Critical Pressure.	Temp. of Saturated Vapor at Atmos. Pressure.		Freezing Point.		Pressure at which Freezing Point was Determ'd. MM.	Density of Gas.	Density of Liquid at Temperature Given.	Color of Liquid.
			Degrees Cent.	Degrees Fahr.	Atmos.	Degrees Cent.	Degrees Fahr.	Degrees Cent.	Degrees Fahr.				
1	Water	H_2O	365	689	200	100	212	0	32	760	.....	1 at .4° C.	Colorless.
2	Hyd. Selenide	H_2Se	185	365	91	− 41	− 41.8	− 68	− 90.4	.....	40	.....	"
3	Ammonia	NH_4	130	266	115	− 33	− 27	− 77	−107	.....	8.5	0.6364 at 0° C.	"
4	Propane	C_3H_8	97	206.6	44	− 45	− 49	Still liquid at −151° C.		.....	20.95	.....	"
5	Acetylene	C_2H_2	37	98.6	.....	− 85	−121	− 81	−113.8	950	12.97	.....	"
6	Nitrous Oxide	N_2O	35	96	75	− 89	−128	−115	−175	760	21.99	.....	"
7	Ethane	C_2H_6	34	93.2	50.2	− 93	−135.4	Still liquid at −151° C.		.....	19.97	.....	"
8	Carb. Dioxide	CO_2	31	88	75	− 80	−112	− 56	− 69	760	21.94	0.83 at 0° C.	"
9	Ozone	O_3	.....	.....	.....	− 93	−135.4	.....	.....	.....	23.89	.....	Dark blue, easily exploded.
10	Ethylene	C_2H_4	10	50	51.7	−102	−150	−169	−272	.....	13.97	.....	Colorless.
11	Methane	CH_4	− 81.8	−115.2	54.9	−164	−263.4	−185.8	−302.4	80	7.98	0.415 at − 164° C.	"
12	Nitric Oxide	NO	− 93.5	−135	71.2	−153.6	−254	−167	−269	138	14.98	.....	"
13	Oxygen	O_2	−118.8	−182	50.8	−181.4	−294.5	.....	.....	.....	15.96	1.124 at − 181.4° C.	Blue.
14	Argon	A	−121	−185.8	50.6	−187	−304.6	−189.6	−309.3	.....	19.9	about 1.5 at − 187° C.	Colorless.
15	Car. Monoxide	CO	−139.5	−219.1	35.5	−190	−310	−207	−340.6	100	13.96	.....	"
16	Air	.....	−140	−220	39	−191.4	−312.6	.....	.....	.....	.....	0.933 at − 191.4° C.	Light blue.
17	Nitrogen	N_2	−146	−231	35	−194.4	−318	−214	−353.2	60	14.01	0.885 at − 194.4° C.	Colorless.
18	Hydrogen	H_2	−234	−389	20	−243	−405	.....	.....	.....	1	.....	"
19	Helium	He	.....	.... .	.....	Below −264	−443.2	.....	.....	.....	2.02		

800, hence we will call the ratio of expansion 800. The volume of one pound of air at 70 degrees Fahr. and atmospheric pressure is 13.36 cubic feet.

The work done in a hyperbolic expansion is, $W = p_2 \times v_2 \times \log_e R$; when

p_2 = final pressure per square foot = 2,117 pounds

v_2 = " volume = 13.36 cubic feet.

$R = \frac{v_2}{v}$ = Ratio of expansion.

$W = 2{,}117 \times 13.36 \times 6.685 = 188{,}000$ foot-pounds.

$\frac{188{,}000}{60 \times 33{,}000} = .095$ = horse-power per pound of air used per hour, and $\frac{1}{.095} = 10.55$ pounds of air per horse-power per hour, if the terminal pressure equals the back pressure, no compression and no clearance being considered.

This result cannot, of course, be realized, for there are many sources of loss which cannot be avoided, and which will make this figure for the weight of air per horse-power hour much higher. However, even if it could be realized in actual practice, it is only just inside of the figure which has been obtained in our best steam engines under practical working conditions.

In these figures the liquid is considered simply as a storage medium for energy, and no account is taken of the amount of heat necessary to develop or store the energy.

In order to get a comparative idea as to the relative values of liquid air and water for power storage, two similar cycles for water will be calculated, and comparative figures obtained.

The range of temperature in the cycle taken for air is from -312 degrees to 70 degrees or 382 degrees.

Starting with water and heating it to 504 degrees under 700 pounds pressure absolute, and expanding it to 2 pounds pressure absolute and 126 degrees Fahr., gives a range of temperature slightly less, viz., 378 degrees. The ratio of expansion will be 254. This final volume of one pound is 172 cubic feet, and considering the expansion to be hyperbolic, we have

$W = 288 \times 173 \times 5.59 = 280{,}000$ foot-pounds; $\frac{280{,}000}{60 \times 33{,}000} = .1415$ horse-power per pound of water used per hour, and $\frac{1}{.1415} = 7.08$ pounds of water per horse-power per hour.

By heating the water to 546 degrees under 1,000 pounds pressure and expanding to atmospheric pressure, the range of temperature would be still less, or about 334 degrees.

The final volume would be 26.3 cubic feet.

Ratio of expansion $\frac{26.3}{.48} = 55.$

$W = 2117 \times 26.3 \times 4.04 = 225{,}000$ foot-pounds.

$\frac{225{,}000}{60 \times 33{,}000} = .1139$ horse-power per pound of water used per hour.

$\frac{1}{.1139} = 8.8$ pounds water per horse-power per hour.

From these figures it will be seen that, under the conditions assumed, water will give off from 20 per cent. to 50 per cent. more energy than liquid air, during expansion through equal temperature ranges. The possibility of the use of liquid air in a prime mover comes from the fact that the upper temperature limit for the range assumed is so low as compared with that for the steam. The upper limit for the air is at 70 degrees Fahr. or 531 degrees absolute, and the possible thermal efficiency is $\frac{191}{531} = .72$; for the water the upper limit is 504 degrees Fahr., or 965 degrees absolute, and the possible efficiency is $\frac{378}{965} = .39$. If the efficiency of the liquid is in any way comparable with that which can be gotten from steam in the steam engine, the efficiency of the air engine should be good. The cost of production of a pound of air would be much greater than that of a pound of steam, so that to be a commercial factor, the efficiency of the air engine would have to be much greater than that of the steam engine. Whether this can be accomplished, the future alone must decide.

As to other uses, refrigeration, medical cautery, prevention of chemical action, explosive compounds, reduction of resistance of conductors for electricity, and use for prevention of the ill-effects of anæsthetics have been suggested, and others will doubtless develop as experiments are tried. It is only within a few months that the liquid could be obtained at a cost that allowed of trial of its properties for any except scientific purposes, where no possible financial return was to be expected and cost was a secondary consideration. With a large supply available, rapid development may be looked for, and new uses will be constantly discovered.

The historical and scientific paper of Mr. Rice was supplemented at the time of its first oral presentation by an exhibition of the physical properties of liquid air and its effects upon substances. A can containing a considerable quantity had been procured for the purpose. It was encased in thick felt, with loose cover, as the liquid could not be contained in a closed vessel.

Some of the air was filtered into a Dewar bulb, which was circulated among those present so that the colorless, slightly blue, limpid liquid could be easily seen. The object of filtering was to remove minute particles of solid CO_2 which would otherwise dull the perfect transparency.

Chemically pure alcohol, freezing at about −202 degrees or −203 degrees Fahr., was solidified, and while dropping in a thick viscous mass from the end of a glass stick was frozen into rigid icicles by pouring the air over it. Mercury freezing, at −39 degrees, was also turned to a fibrous solid, being frozen into a rectangular block 1¼ inches square, with an eye screw in either end. Ropes being run through the eyes, it carried 170 pounds swinging on it.

Rubber immersed in the air was made brittle like china, paraffin crumbled in the hand like chalk, meat turned to stone, and a rose dipped into it shattered on striking the table like delicate glass.

Pieces of iron and tin were rendered brittle by immersion, so that they broke in the fingers or under the hammer like glass. Copper, however, did not lose its ductility (so also with the "royal" metals).

Liquid air poured in water at first floated, but as the nitrogen, being the first to evaporate, boiled off, the heavier oxygen sank in globules. Practically liquid oxygen being gotten by allowing a beaker filled with air to stand some time, a piece of felt that would not burn of itself, even though fairly ignited over a bunsen burner, was dipped in it, after which combustion was complete and immediate. Cotton so immersed burned with almost explosive violence. A steel watch spring and an arc-light carbon burned with intense brilliancy in it. A wrought-iron tube was shown bent and torn into ribbons by the explosive combustion in one end of it (while open at both ends) of a small amount of cotton waste dipped in oil and air.

The retarding effect of extreme cold upon chemical action

was shown by the reluctance of sodium to burn in water, after immersion in the liquid air; when it lost the chill, combustion took place.

The fact that below the critical temperature mere cold would liquefy air, was demonstrated by putting a small amount of liquid air in a long-necked bulb, to the end of which was connected a toy balloon. The balloon expanded till all the liquid in the bulb was evaporated, thus leaving nothing but gaseous air at practically atmospheric pressure. The bulb was then immersed in liquid air, and gradually the balloon contracted till the liquid put in the bulb again appeared and was poured out onto the floor.

The means of measuring this degree of extreme cold were mentioned, with their probable unreliability. The hydrogen thermometer introduced a possible element of considerable error in that, at the temperature of liquid air it is used near its own critical temperature. In the use of the thermopile it is assumed that the law which governs its temperature curve at normal temperatures holds good throughout, and exterpolation thus made may be in considerable error. The platinum thermometer usually used is probably most nearly correct, as its resistance curve is practically a straight line, which extended passes through the origin of coördinates, and there is little reason to suppose it does not actually do so.

Wherever the liquid was exposed to the air, dense clouds of congealed vapor formed and fell to the floor, and small bulks of the liquid thrown in the air or on table or floor immediately evaporated, though in a Dewar bulb a quantity will keep for hours. If allowed to rest on the flesh, the liquid air immediately raises a blister with the sharp pain of burning.

No. 831.*

EXPERIMENTS ON USING GASOLINE GAS FOR BOILER HEATING.

BY HERMAN POOLE, NEW YORK CITY.
(Member of the Society.)

LAST year I became interested in some experiments where air gas made with gasoline was used. The principal point to be settled was if it could be used to get up steam in a boiler, and if so, at what cost.

The experiments were made at Philadelphia with a 60-horse-power boiler. The details are given below. The results showed that steam could be raised in a boiler with gasoline gas as a fuel, but as compared with coal it was much more costly.

Details of the Apparatus Used.

The boiler used was of the common compound tubular pattern, made of $\frac{5}{16}$-inch iron, and set in brickwork in the ordinary manner. It was situated in a building separated from the mill proper, and so arranged that it could be entirely cut off from all connection with the other portions of the mill. It was not then in use, and had not been for several months. Previous to beginning the experiments, the flues and fire sheets were thoroughly cleaned.

The dimensions were as follows:

Boiler: Length, 14 feet; diameter, 42 inches; containing 38 flues, 3 inches in diameter. Thickness of iron, $\frac{5}{16}$ inch.

Superheater: Length, 14 feet; diameter, 36 inches; connections, two in number, being vertical pipes 3 feet 8 inches high and 1 foot in diameter.

The fire sheet was 14 feet long, 5 feet 8 inches wide; top sheet of superheater 14 feet long by 1 foot 8 inches wide, the bottom

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

sheet being 14 feet long by 6 feet wide. The quantity of water was 1,500 gallons, or 12,000 pounds.

Water-heating surface—		
Of the boiler	520	square feet.
Of the superheater	111	" "
Total	631	" "

At the top of the superheater were two 3-inch safety valves with adjustable blow-off. The boiler was tested for 150 pounds; but when in use the pressure never exceeded 100, and was generally 75 to 80 pounds.

The fireplace was 3 feet 8 inches deep, 5 feet 5 inches wide, 16 inches high at the front, and 5½ inches from top of bridge wall to boiler. The grate area was a fraction less than 20 square feet. The grate bars were of the ordinary cast-iron pattern, running from the doors back to the bridge.

The front was of cast iron about ⅝ inch thick, and had openings for the superheater, boiler tubes, and the two doors. The opening for the ash-pit was a flat arch and had no door. The fire-door had small openings in the centre, which could be closed at will. For the first experiment this opening was bricked up tight. It was afterwards opened, and remained so. The brickwork enclosed the boiler on all sides except the front. It was 18 inches thick and in very good condition, no leaks or cracks being visible on inspection. The walls were close to the boiler on the sides and about 24 inches from the boiler at the back. In the side wall of the brickwork, about 4 feet from the rear wall and at convenient height, was placed an opening containing an iron pipe. This was for the double purpose of an observation hole and an opening to receive a pyrometer if deemed advisable.

Leading to the left of the boiler, at the rear end of the brick wall, was the flue to the chimney. This flue was 24 inches square inside and was furnished with a square cast-iron damper suspended near the chimney by a balanced cord and moving easily up and down. An opening was made in the top of the flue 21½ inches from the damper to admit the thermometer well. This consisted of a 2-inch pipe 18 inches long, closed at the lower end and open at the upper one. It was to be filled with paraffine wax in which would be placed the thermometer to register the temperature of the water gases. The flue was about

5 feet long, and emptied into the chimney, 2 feet 2 inches square and 65 feet high. It had an iron door about 15 inches square at the base for cleaning.

The gas machine was built especially for these experiments, and consisted of a carburetting cylinder, a mixing cylinder, and a generating cylinder. The carburetting cylinder contained an arrangement for saturating the air with the gasoline, and had a false bottom containing a steam heater to assist in the vaporization. The mixing cylinder was simply to add more air to the mixed gases from the other two. The generating cylinder contained dilute sulphuric acid acting on zinc and generating hydrogen. By our method of working, the air was pumped into the generator and the carburettor, and then these two different kinds of air were mixed with more air in the mixer and passed on to the burner. The quantity of hydrogen generated in these experiments was so small that it had no influence on the results obtained, the gas burned being substantially a gasoline-saturated air.

In the first experiment the air could not be called saturated, but was more properly a gasoline vapor carrying some air. In the other two the proportion of air was much greater, and more as it should be for good combustion. The carburetting liquid used was 88 degrees gasoline. It was contained in a barrel set up on a staging in the yard some 10 feet away from the machine. The barrel connected with the machine by means of a $\frac{1}{2}$-inch gas pipe having two stopcocks.

For the first experiment the blower used was a small Westinghouse, connected directly to a small 10-gallon kitchen-range boiler, serving as a reservoir to equalize the pressure. From this it was connected to the gas machine through a $\frac{1}{2}$-inch pipe, and also by a side opening to the burner under the boiler. This blower was supplemented later by a 16-inch rotary fan blower and by a No. 2 P. H. & T. M. Root blower. When the rotary blower was used, it was connected with the burner direct to supply air to the mixer. When the Root blower was used, the reservoir was dispensed with, and the blower was connected direct to the machine and the burner, a blow-off opening being provided to relieve pressure when necessary.

The first burner used was made of a piece of 5-inch gas pipe 5 feet long, having $\frac{1}{2}$-inch holes 6 inches apart along its length. In these holes were screwed 6-inch pieces of $\frac{1}{2}$-inch pipe with

the free ends pounded down so as to make a flat tip, the opening in some cases being only $\frac{1}{16}$ inch across, in others more, but in none more than $\frac{1}{8}$ inch. This burner was placed in the fireplace just inside the door openings, running lengthwise of the boiler front, the holes and jets looking backward and a little inclined above the horizontal. The space under the pipe was filled with fire-clay and brick. The pipes rested on fire-brick, and the whole was partially enclosed by piling loose brick over it. One end of the large pipe passed out through the brickwork of the boiler, and was connected with the gas machine by means of a pipe having a stopcock just outside the brickwork, and with the blower by means of a separate pipe which also carried a valve. The gas-supply pipe was 1 inch in diameter, and passed into the large pipe some 8 or 10 inches, opening just behind the first jet in the fireplace. At first the pipe was used with the full opening. Afterwards the opening was reduced to about one-half.

The second burner used was made from the one just mentioned by removing the jets, increasing the size of the holes to 1 inch, and running the gas-supply pipe the whole length of the large pipe, making openings and jets from it to the holes of the large pipe, into which they opened just inside the large pipe. The connections outside the boiler were changed so as to connect with the gas machine direct as before, and with the blower for an air supply by means of a 2-inch pipe. This pipe was supplied with cocks for regulating the air supply, both to the gas machine and to the burner. A blow-off was also placed on the main line to relieve pressure if necessary.

Both burners were covered with a few fire-brick placed about 1 inch apart. With the first burner this arrangement was maintained throughout the trial; with the second one it was kept only during the first half of the time, as the burner became so hot that softening was feared. The bricks were then removed, part of them being taken out and pushed back.

The Experiments.

Experiment No. 1.—The first experiment was made April 12, 1898. The boiler and chimney were cold, and had not been used for several months. The gas was turned on about noon, and after several extinguishings and relightings was finally

lighted at about 2.30 P.M., and allowed to burn to ascertain if the water could be heated, no account being taken of the quantity of material used. The combustion was very poor, the gas being too rich in hydrocarbon, and large quantities of carbon passing away unconsumed, as was shown by the dense smoke rolling out of the chimney. The damper was full open at the commencement, but was shut down three-quarters early in the run.

Air was forced into the burner by means of the blower, but this had the effect of driving the larger portion of the gas to the farther half of the burner, thus depriving the left-hand side of the boiler of a large portion of the flame. On the right-hand side the flame passed off in the angle between the boiler and the brickwork, not doing any efficient work until it reached the flues. At no time was the entire under sheet of the boiler covered with flame. Owing to the imperfect combustion the flame burnt smoky, and large quantities of soot were undoubtedly deposited on the boiler. At no time was the supply of air sufficient. After running for three hours and consuming three-fourths of a barrel of gasoline, the boiler showed some ten pounds steam pressure. As the object was simply to ascertain if steam could be made, and as the construction was decidedly imperfect, no data were taken of the test. The result was satisfactory for the object in view, but not on general principles. It was proved that the gas had heat, that the heat could be used, and that it could be utilized under a boiler. There were so many drawbacks to a satisfactory result economically that it was not considered.

Experiment No. 2.—This was made April 13, 1898, and while only a short and tentative one and very incomplete, yet developed many more possibilities than were shown at the previous test.

A consultation was had, resulting in a change in the working of the machine, and the consequent production of a much more suitable gas and a much larger and more thorough admixture of air. The burner and other apparatus were the same as before, no change being made in them. The gas was lighted at about noon, and was burned for some 20 to 25 minutes. The water at the commencement had a temperature of about 100 degrees. The flame was quite satisfactory, both as to quality and quantity, showing perfect combustion, with no smoke from the chimney top. Occasional puffs of white mist could be seen, but nothing which could be called smoke. The water in the boiler was heated to boiling, and soon indicated pressure on the gauge. As this was only to

determine the effect of the change in the working of the gas machine, and as the result was satisfactory, it was soon discontinued, no further information being possible under the circumstances. After this trial was over a consultation was had, and a number of changes suggested. Among them was the production of a modified burner to consist of the old burner changed in one of two ways. One method suggested was to remove the 5-inch pipe, make some more openings in it on the side opposite those now existing; to screw in pieces of 1-inch pipe on both sides of this piece, making them long enough so that the entire length should be the depth of the fire grate. These small pipes were to have holes on the top for the escape of the gas. The other method was to use the same large pipe, and have it run along in front of the doors, the smaller perforated pipe to run from this back to the depth of the fire surface. Outside, the larger pipe was to be connected with a larger one to serve as a mixer, into which the gas-supply pipe should empty, and by its force draw in the requisite air supply previous to reaching the 5-inch pipe. By this arrangement the use of the blower would be obviated, and the gas mixed with air would be delivered at the burner under the least possible pressure. The small Westinghouse blower was to be removed and a larger positive blower put in its place. The necessary changes in piping were to be made, and a fresh barrel of gasoline obtained.

Experiment No. 3.—This experiment was made on April 21, 1898. The burner had been changed, but not as was expected and as described above; the main difference from the former burner being that the arrangement of gas openings in the air openings did not allow proper mixing before burning; consequently, more air was used than should have been necessary, and a consequent loss of heat resulted in an increased quantity of waste gases to pass off at the chimney. The burner was covered with brick, as before, and the under portion bedded in fire-clay and brickbats. The small 2-cylinder blower had been removed and a No. 2 Root blower substituted for it. The small kitchen boiler as receiver had also been removed. The connections were substantially as before, except that a blow-off had been provided for the blower to use in case too much air was forced into the pipes. A small rotary blower was used also to furnish air to the mixer. The flame produced was generally good, but not regular, the Root blower being too large to be

run at a proper speed; consequently, the air came in puffs. This, while not producing a satisfactory flame, gave a much better one than that used in the first experiment, being well distributed over the bottom of the boiler and causing the fire-brick lining of the fireplace to become red hot. But very little smoke escaped at the chimney top, most of the time nothing being visible; at intervals a faint white mist was to be seen, especially toward the end of the run. This may have been due to condensed moisture. Considering the unsatisfactory form of burner used, this result may be called good. The temperature of the water was 50 degrees Fahr. at the commencement; the chimney and all the brick and iron work were of the same temperature. The quantity of water contained in the boiler was 1,500 gallons.

The boiler showed the effects of the fire in a few minutes, and in 1 hour 25 minutes steam was seen to issue from the open try-cock. The fire was kept up, the pressure carried to 60 pounds, and maintained at that point, both safety valves being kept open and blowing all the time. As in the previous experiments, the burner was loosely covered with fire-brick during the first part of the test; but the heat being so great locally from reflection back to the burner, the pipe soon became yellow hot, and to prevent softening the bricks were pushed back out of range of the flame. The damper was wide open at starting, as in the other trials. As soon as combustion and draught were fairly established, it was gradually lowered to about 1 inch opening. The holes in the furnace doors were kept open some time longer, but were finally closed up, all the air being admitted at the burner. The quantity of heat passing off in the waste gases to the chimney was quite small; as at the beginning of the test, full 20 minutes was required to melt the 125 degrees paraffine wax contained in the thermometer well. Definite observations of the temperature were not possible, as the quantity of wax provided for the well was only about one-half the necessary amount, and it could hardly be reached by the thermometer bulb.

The heat passing off by radiation was not excessive, as the brickwork did not become warm to the hand. Of course a larger proportion of heat was used in warming up the bricks than would be with a larger rim. No flame or reflection could be seen through the observation hole at the back of the boiler, showing that nothing but the heated gases reached that portion.

Cost.

The quantity of gasoline used was 35 gallons, costing 10 cents per gallon. This generated 1,000 pounds of steam at 60 pounds pressure, equivalent to 1,211 pounds evaporated from and at 212 degrees.

It was intended to have a full time experiment of 8 to 10 hours, so as to obviate some of the many uncertainties; but this was not carried out, and the paper is presented as simply a contribution to the subject, but not as one settling any important questions except the item of cost. It will be readily seen from the test experiments that, if cost of fuel is to be considered, the cost of gasoline and allied substances is entirely out of the question. The same amount of work can be performed with coal as fuel for not more than one fourth the expense, and the danger of using such volatile and inflammable materials obviated.

SUMMARY OF DATA AND RESULTS.

Time of trial	about 2 hours
Grate surface	3 ft. 8 in. by 5 ft. 5 in., or 19.9 sq. ft. of area
Water-heating surface	520 sq. ft.
Superheating surface	111 sq. ft.
Total	631 sq. ft.
Ratio of water-heating to grate surface	26 to 1
Ratio of minimum draught area to grate surface	1 to 12
Steam pressure	60 lbs.
Temperature of air	50°
" boiler room	80°
" steam	307°
" feed-water	(none used)
" waste gases at chimney	(not taken, estimated at 325°)
Fuel used	air-gasoline gas
Analysis of gas	(not made)
Quantity of gas used	(not measured)
Weight of oil	227.5 lbs.
Calorific value per pound	20,000 B. T.
Total weight of water in boiler	12,500 lbs.
Weight of water evaporated	1,000 lbs.

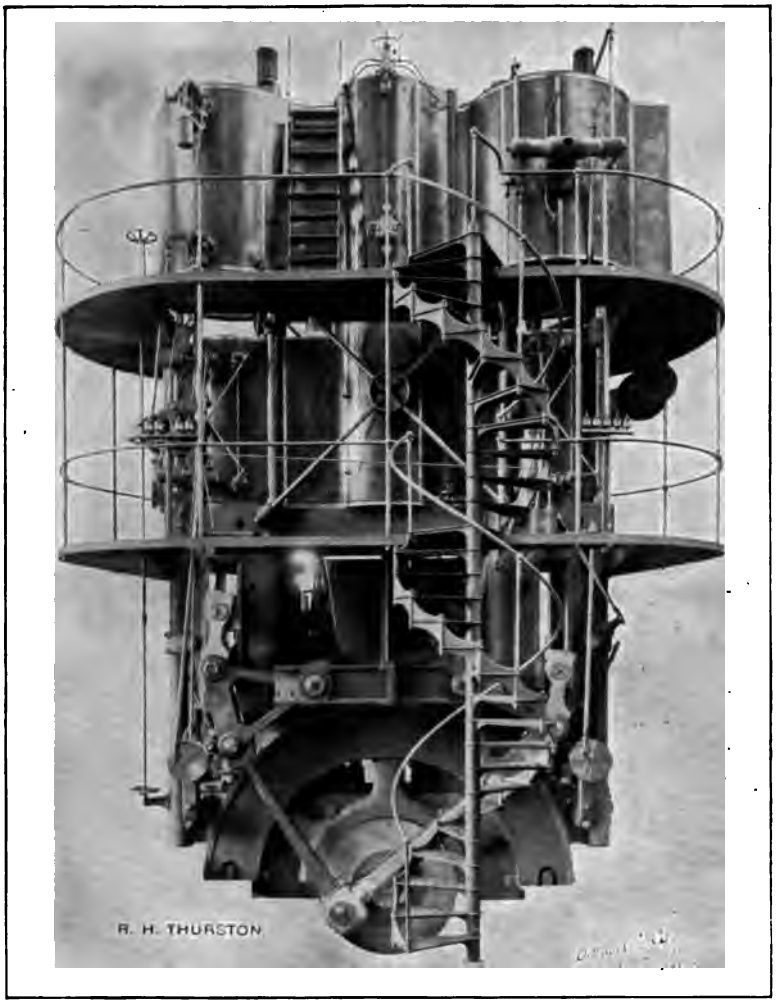


FIG. 20.—QUADRUPLE-EXPANSION ENGINE.

No. 832.*

THE STEAM ENGINE AT THE END OF THE NINETEENTH CENTURY.

BY R. H. THURSTON, ITHACA, N. Y.

(Member of the Society and Past President.)

INTRODUCTORY.—In September, 1898, the writer was asked to take part in an official trial of a steam pumping engine, then completed, which illustrated some peculiar arrangements for heat transfer, and which was expected to exhibit an exceptional efficiency as a consequence of its unusually close approximation to the Carnot cycle. The engine had been in operation since the beginning of that year, and its preliminary trials by its constructors had, as it was stated, given unprecedentedly high values of duty and efficiency. It seemed thus possible that the engine might have a vastly higher interest, scientifically and as a matter of applied thermodynamics, than as simply a steam pumping engine exhibiting exceptionally high duty, and it was suggested by the writer to the representative of its proprietors and the builders that a more satisfactory arrangement, all around, might be one which would allow of the scientific study of the machine as a thermodynamic engine; in which case, if the data were permitted to be published in full, with deductions, if found instructive, the engine trials made to secure them might be conducted as part of the scientific work of the Department of Experimental Engineering of Sibley College. This was found mutually satisfactory; the direction of the work was undertaken by Professor Carpenter, and the data so obtained are now and here presented as illustrating the approximation attained by

---

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

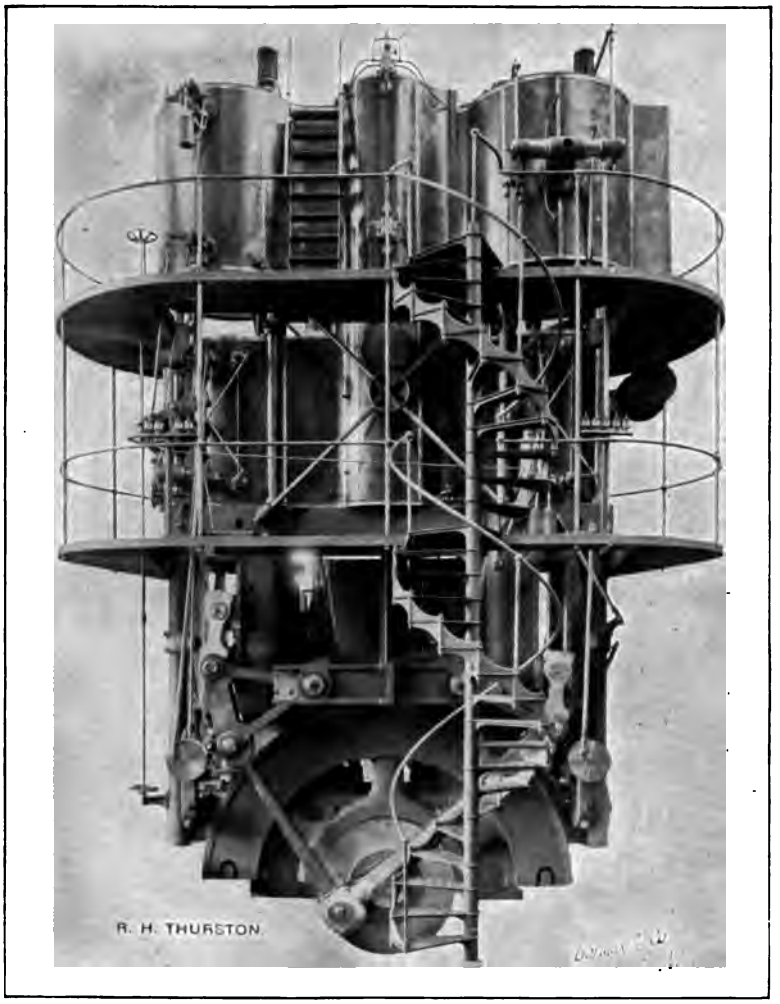


FIG. 20.—QUADRUPLE-EXPANSION ENGINE.

differing greatly from one another and progressively decreasing. (Page 115, translation.)

We should not expect ever to utilize in practice all the motive power of combustibles. . . . The economy of combustible is only one of the conditions to be fulfilled in heat engines. In many cases it is only secondary. It should often give place to safety, to strength, to durability of the engine, to the small space it must occupy, to small *cost* of installation, etc. (Page 126, translation.)

Carnot even recognized the advantages of the compound engine, and described those of Hornblower and of Woolf. (Pages 118, 256, translation.)

He makes the thermodynamic efficiency, as a maximum, the quotient of the range of temperature worked through by the total absolute temperature of the initial stage of expansion. His deficiencies from the point of view of the thermodynamist were corrected by Lord Kelvin, in 1849.*

Later researches by Joule and his successors have confirmed the work of Count Rumford and Sir Humphrey Davy, and of Mayer and other pioneers in the development of the science of thermodynamics, and it is now known that 778 foot-pounds of energy is very exactly the dynamic equivalent of one British thermal unit, and that 2,545 British thermal units per hour or 42.42 per minute represent the thermal equivalent of the horse-power; while the quantity of heat demanded by any heat engine of efficiency less than unity, as E, is measured by either $2{,}545/E$ or by $42.42/E$, accordingly as the time unit is the hour or the minute.

The Carnot efficiency, in British heat units per horse-power gives

$$H_c = 2{,}545\left(\frac{T_1}{T_1 - T_2}\right) \text{ per hour;}$$

$$= 42.42\left(\frac{T_1}{T_1 - T_2}\right) \text{ per minute;}$$

the Carnot efficiency being $E_c = \frac{T_1 - T_2}{T_1}$; where T is the absolute temperature.

* "Transactions Royal Society of Edinburgh, 1849;" Appendix to Thurston's translation of Carnot, previously cited, pages 127–203.

The Ideal Engine.—The following tabulated values of E and of A (Table I.) are the ideal maxima for efficiencies of the ideal perfect heat engine, whether steam or other, and quantities of heat demanded per horse-power per hour; the lower, constant, limit of temperature being taken as, in the condenser, 126 degrees Fahr. (52.2 degrees C.), corresponding to 2 pounds pressure or 26 inches vacuum, and the upper as ranging from the lowest to the highest limits of temperature and of pressure in modern steam boilers, from $p = 150$ to $p = 500$ pounds per square inch.* Table II. gives similar figures for corresponding ideal Rankine cycles having complete expansion; the difference between the Carnot and the Rankine cycles in these cases being simply that the one set illustrates complete mechanical compression from the lower to the higher limit of temperature and pressure and the other exhibits no compression, and the change from the lower to the higher limit must be effected by heat from the furnace.

The study of these figures and their comparison will prove most interesting as illustrating the method of gain and its extent, in each cycle, and the influence of change of form of cycle at each pressure.

TABLE I.

CARNOT CYCLE.

Ideal case; $p_2 = p_3 = 2$; corresponding to $T_2 = 587°$.

p_1	150	200	250	300	350	400	450	500
T_1	819.2	841.6	861.9	878.36	892.9	905.92	917.6	928.4
r	44.8	57.8	70.4	82.63	94.6	106.5	118	129.6
V_3	133	130.4	128.4	126.83	125.4	124.2	123.3	122
H_1	671,000	656,000	646,097	636,604	628,219	620,797	613,000	607,618
U	190,000	198,500	205,000	210,079	218,900	218,500	221,000	222,000
E	28.3	30.3	31.9	33.1	34.2	35.1	36.	36.7
M.E.P.′	1,427	1,522	1,604.9	1,695	1,712.1	1,758.2	1,800	1,820
M.E.P.″	10.01	10.56	11.13	11.55	11.85	12.2	12.5	12.7
A	9,000	8,430	7,986	7,780	7,450	7,236	7,050	6,934
B	2.95	3.02	3.08	3.11	3.15	3.19	3.23	3.26
C	10.45	9.98	9.69	9.4	9.2	9.0	8.94	8.89
W	9.32	8.73	8.27	7.93	7.73	7.49	7.32	7.19
F	.90	.832	.799	.773	.745	.724	.705	.698
D	1,390	1,300	1,236	1,190	1,157	1,115	1,100	1,090
D'	22.8	21.7	20.6	19.9	19.28	18.58	18.3	18.1

* "Standard of Efficiency for Heat-Engines," *Journal Franklin Institute*, December, 1896, January, 1897, R. H. Thurston; also "Manual of the Steam Engine," fourth edition, p. 1002.

TABLE II.

RANKINE'S NON-CONDUCTING CYCLE.

Ideal case; $p_2 = p_3 = 2$; condensing; $T_3 = 587°$.

p_1	150	200	250	300	350	400	450	500
T_1	819.22	842.63	861.88	878.369	892.96	905.9	917.62	927.2
r	14.87	19.34	25.	27.4	31.4	35.4	39.17	43.02
V_2	44.04	43.25	42.6	42.06	41.55	41.25	40.82	40.5
H_1	858,289	863,813	868,411	872,328	875,827	878,890	881,707	885,000
U	197,624	212,305	223,805	233,120	232,231	242,042	256,526	262,050
E	23.	24.5	25.87	26.7	26.5	27.5	29.09	29.6
M.E.P.' ..	4,521	4,908	5,188.7	5,260	5,583	5.875	6,170	6,375
M.E.P.'' .	31.16	34.2	35.5	36.6	38.77	40.75	42.64	45.5
A	11,065	10,386	9,910	9,875	9,608	9,254	8,748	8,600
B	2.3	2.29	2.28	2.27	2.26	2.25	2.25	2.24
C	10.	9.35	8.88	8.52	8.54	8.36	7.7	7.57
W	11.4	10.7	10.3	10.2	9.9	9.2	9.0	8.9
F	1.107	1.03	.991	.987	.96	.925	.875	.843
D	440.4	397.	387.1	376.2	355.	328.	316.	306.3
D'	7.3	6.7	6.4	6.2	5.9	5.6	5.3	5.1

The symbols employed have the following significations: *

p_1 = initial pressure in pounds per square inch, absolute.

p_2 = pressure at the end of expansion.

= back pressure. Expressed in pounds per square inch, absolute.

v_1 = initial volume.

= volume in cubic feet of 1 pound of dry and saturated steam at initial pressure.

v_2 = volume in cubic feet at the end of expansion =

$$\frac{1}{\frac{dp_2}{dT_2}}\left[J \log_e \frac{T_1}{T_2} + v_1 \frac{dp_1}{dT_1}\right]$$

$$= v_1 \left(\frac{p_1}{p_2}\right)^{.881}; \text{ where } .881 = \frac{1}{1.135}, \text{ nearly.}$$

T_1 = absolute temperature in degrees Fahr., corresponding to p_1.

T_2 = absolute temperature in degrees Fahr., corresponding to p_2.

L_1 = latent heat of evaporation, corresponding to p_1.

r = ratio of expansion.

$$= \frac{v_2}{v_1}.$$

* "Steam Engine," chap. iv., p. 104, *et seq.* Thurston's "Manual," chap. v., vol. i.

H_1 = heat expended per pound of steam, expressed in foot-pounds.

$= JL_1$.

$J = 778$.

Efficiency $= \frac{T_1 - T_2}{T_1}$.

U = net work done per pound of steam, expressed in foot-pounds.

$= H_1 \times$ Efficiency.

M.E.P.$' = \frac{U}{v_2}$ in pounds per square foot.

M.E.P.$'' = \frac{\text{M.E.P.}'}{144}$ in pounds per square inch.

A = British thermal units per indicated horse-power per hour.

$= \frac{2{,}545}{\text{Efficiency}}$.

B = pounds of steam per indicated horse-power per hour for efficiency unity.

$= \frac{1{,}980{,}000}{H_1}$.

C = pounds of steam per indicated horse-power per hour for actual efficiency.

$= \frac{B}{\text{Efficiency}}$.

W = equivalent "water-rate" from and at 212 degrees Fahr.

$= \frac{A}{966.069}$.

F = pounds of fuel per indicated horse-power per hour, at 10,000 British thermal units per pound, net.

$= \frac{A}{10{,}000}$.

D = piston displacement per indicated horse-power per hour.

$= Cv_2$ cubic feet.

D' = piston displacement per indicated horse-power per minute.

$= \frac{D}{60}$.

The Corliss or Rankine Cycle, even, as is not usual, where expansion is complete from the initial to the back-pressure line, differs from the perfect engine cycle, as is evident at a glance, markedly in the omission of the compression line which carries

the temperature of the working fluid from the minimum to the maximum limit of pressure and of temperature without abstracting from the heat supply of the boiler. It is further easily shown, by direct measurement or computation, that the waste of heat produced by omission of the Carnot system of mechanical compression is much greater than the gain of work due to increased area in the Rankine diagram.* The difference measures the defect of efficiency of the Rankine cycle when compared with that of Carnot. Could this defect be remedied, we should have the Corliss cycle, as illustrated by the indicator diagrams of properly adjusted engines, to this degree more nearly perfect. The remedy may be found in either of three ways: (1) adopt such a construction of engine as will produce full compression of the whole working charge, as in the Carnot cycle, or (2) secure the same result—the elevation of the temperature of the feed-water to that of the prime steam—by Cotterill's plan of directly transferring heat from the expansion side, or (3) adopt the Sterling "regenerator system," if that can be made practicable. It is obvious that it is a matter of indifference whether the cycle be the standard perfect engine cycle, the proposed form, the regenerator cycle, or any other, if any other there be, which insures the transfer of energy to and from the working substance at the opposite extremities of the indicator diagram in such manner as to produce the result prescribed by Carnot—the receipt at maximum temperature of all heat accepted into the cycle, and the rejection at minimum temperature of all heat thrown out from the system. Any cycle which, at the end of the induction period of the diagram, or the point of cut-off in the case of the steam engine, produces abstraction of heat sufficient to reduce the pressure and temperature of the charge to the minimum back pressure and temperature, and which, later, at the close of the exhaust period of the ordinary diagram, utilizes that quantity of energy in the restoration of temperature and pressure to the maximum—no matter whether the intermediate storage occurs in form of thermal or of dynamic energy—will be the thermodynamic equivalent of the perfect engine cycle, and will exhibit the same thermodynamic efficiency. This statement may be taken as the generalized theorem of cycle equivalence and to include that principle and that pro-

* "Manual of the Steam Engine," vol. i., sec. 205, p. 798.

posed method of operation which has been described as original with Cotterill. Of this class are all cycles composed of a pair of isothermals crossed by a pair of isodiabatics.

The losses due to defects of Rankine's cycle ordinarily range thus for condensing engines *:

Losses per cent. Total.		Losses per cent. Work.	
Loss by non-compression.....	5 to 15	Measure of useful work.....	40 to 60
" " incomplete expansion.	50 to 75	Loss by non-compression.....	3 to 6
" " back pressure.....	45 to 10	" " incomplete expansion.	30 to 30
		" " back pressure.....	27 to 4
Total loss, per cent.....	100	Total Carnot, per cent.....	100

Comparisons of Ideal Cycles, as of that of Carnot with those of Rankine, jacketed and unjacketed, and also condensing and non-condensing, with equal total maximum ranges of temperature and pressure between boiler and condenser, or between initial and final cycle limits, are very instructive. For example, in the following table we have the computed efficiencies of the Carnot, the non-conducting cycle of Rankine, and the ideal "jacketed engine cycle" of the latter, where the initial pressure is 400 pounds per square inch above vacuum, and the lower limit is taken for all at 2 pounds, absolute, for Cases I., and at 16 pounds, absolute, for Cases II.; all being purely thermodynamic cases, and no other wastes than those of these thermodynamic cycles being assumed. The third form of cycle, obviously and necessarily in this case, proves a more inefficient case than the non-conducting engine cycle; since the jacket expenditure is thermodynamically a waste, though in the case of the real engine it is advantageous as usually checking a more serious waste to such extent as to give, as a rule in that case, a net gain by use of the jacket.

The study of such data as are presented in these three tables is particularly instructive, helpful, and interesting to the engineer, as exhibiting, by comparison with the data derived by tests of existing engines of the record-breaking classes, the still remaining defect of efficiency in the latter, the remedy of which still remains his great standing problem.

---

* "Manual of the Steam Engine," vol. i., sec. 205, p. 799, etc. See particularly: Cotterill, "The Steam Engine as a Thermodynamic Machine."

TABLE III.

RELATIVE EFFICIENCIES OF STEAM-ENGINE CYCLES.

Ideal cycle ; $p_1 = 400$ pounds per square inch.

p_2 for cases I. = 2, for cases II. = 16.

	CARNOT CYCLE.		RANKINE NON-CONDUCTING ENGINE CYCLE.		RANKINE JACKETED ENGINE CYCLE.	
	I.	II.	I.	II.	I.	II.
r	91.23	17.85	35.3	13.7	45.3	16.14
v_2	106.45	20.83	41.2	16.06	52.89	18.84
p_1, pounds per square foot	57,600	57,600	57,600	57,600	57,600	57,600
p_2 " " "	288	2,304	1,008	3,024	1,008	3,024
p_3 " " "	288	3,304	288	2,304	288	2,304
T_1 (absolute)	905.92	905.92	905.92	905.92	905.92	905.92
T_2 "	587.3	677.347	639.9	691.56	639.94	691.56
T_3 "	587.3	677.347	587.3	677.347	587.3	677.34
T_4 "	905.92	905.92	581.	661.	581.	661.
H_1	620,797	620,797	898,806	816,666	878,806	816,666
U	218,332	157,062	250,470	169,937	267,420	198,365
Efficiency, per cent. (computed).	35.17	25.3	28.5	20.82	25.55	17.9
M.E.P.', pounds per square foot	2,050	7,540	6,079	10,581	5,056	10,529
M.E.P.'', pounds per square inch	14.2	52.4	42.2	73.48	35.11	73.1
A, B.T.U. per H.-P. per hour	7,236	10,059	8,930	12,235	9,960.9	14,220
B, pounds steam per H.-P. per hour for efficiency = 1	3.19	3.19	2.36	2.42	2.25	2.42
C, pounds steam for computed efficiency	9.07	12.6	8.28	11.68	8.8	13.5
W, "water-rate" from and at 212° Fahr	7.49	10.41	9.24	13.66	10.3	14.7
F', pounds fuel for computed efficiency	.83	1.15	.92	1.168	.978	1.35
D, piston displacement per I.H.P. per hour	976.1	262.46	341.1	187.58	465.4	254.3
D', piston displacement per I.H.P. per minute	16.27	4.374	5.68	3.126	3.25	4.24

The Fundamental Principle characteristic of the Carnot engine cycle may be thus stated: *All heat received into the engine should be absorbed at the maximum temperature of the cycle; all heat rejected should be discharged at the minimum temperature of the cycle.*

This principle being adhered to, it follows that all changes of temperature must, in such cases, be produced by the alternate conversion of heat of internal energy into work by expansion, during the period of reduction from maximum to minimum temperature, and by re-transformation of work of compression into such heat during the period of restoration from minimum to maximum temperature of working fluid, *or by equivalent devices.*

An equivalent device, *e.g.*, would be the adoption of the "regenerator principle," by which, were it practicable, all heat rejected in the process of reduction of temperature from maximum to minimum should be taken into a "regenerator" or heat storehouse, and from this, later, returned in the process of elevation of the temperature from minimum to maximum. The Stirling ideal gas engine, for example, illustrates such a case, and it is entirely conceivable that some such method, exact or approximate, might be employed in the steam engine to confer upon its cycle the properties of that of Carnot. In fact, such an idea has been suggested by Cotterill, and is to be described presently.*

The ideal Carnot elementary cycle may be described as one in which the work produced is the difference between that of expansion at constant, maximum, temperature and that of compression at minimum, constant, temperature; the work of compression with increasing temperature and that of expansion with decreasing temperature being means of adiabatically changing temperature between the limits of the cycle. Whether the alteration of temperature is effected by means of such temporary storage of energy in form of either heat or of work, whether in the flywheel or in a regenerator, is unimportant, *provided* that all which is stored in the process of reduction of temperature is restored, by precise reversion of action, in the process of elevation of temperature. It is obvious that increasing efficiency in the common type and of the standard cycle of the steam engine may be the result of any device which gives closer approximation either to the ideal Carnot or to the equivalent ideal Stirling type cycle. In the engine presently to be described, the unexampled "duty" is, in part, at least, due to some advance toward such an approximation to the cycle of Carnot; effected by application of Cotterill's idea in a practicable manner by the adoption of special devices in construction.

Cotterill called attention, some years ago, to the fact that there were conceivable methods of improving the efficiency of the steam engine by closer approximation to the Carnot cycle on the compression side of the cycle of the real engine. †

The now usual arrangement of auxiliary engines, feed pumps, independent air pumps, etc., with exhaust steam carried into the

* "The Steam Engine considered as a Thermodynamic Machine"; London and New York, E. & F. N. Spon, 1890, pp. 235, 362, 420.

† "The Steam Engine," 2d edition, 1890, sec. 164, pp. 235, 362, 420.

boiler, after being condensed in the feed-water, illustrates the case, and it will be seen, on study of the action of these auxiliaries, that aside from wastes by external conduction and radiation, they are operated with only that expenditure of heat which is the mechanical equivalent of the work performed by them. All heat not converted into work, as in the case of the injector, goes back into the boiler. The mean total efficiency of the whole system of main and auxiliary engines is thus increased, though, in the average case, not very greatly.

Similarly, feed-heating, by steam from the intermediate reservoirs of the engine, by steam whose heat has performed some work already, and which is thus returned to the boiler through the feed-water heating system, to the extent to which this becomes practicable, is also illustrative of such a gain and, in practice, this may amount to several per cent.

The Ideal Feed-Water Heater would be one which, taking heat from the expansion side of the cycle, restores it, at its own maintained temperature level, on the compression side, in such manner as to imitate, in a way and to a maximum extent, the "regenerator action," which has been seen to be the ideal equivalent, economically, of the balanced expansion and compression energy transfers of the Carnot cycle. Could a way be found of taking out all the needed heat from the steam, between initial and back pressures, after the point of cut-off is reached, and of restoring it all, at unchanged temperature level, at the completion of the return stroke of the piston, equivalency with the Carnot cycle would be complete. The cycle would consist of isothermals crossed by isodiabatics or an equivalent.

Cotterill has suggested the ideal arrangement of a feed-water heater consisting of a series of tubular gratings, each receiving and discharging the heat to be stored or restored at its own special temperature; these temperatures of the several bars of the grating being graded from the maximum to the minimum, thus permitting a step-by-step system of transfer of heat between the two sides of the cycle.*

Were it to prove practicable to divide the expansion period of the cycle into a considerable number of parts, and could a way be found of transferring heat, at the last step of this progression, directly from the expansion side to the feed-water

---

"The Steam Engine," 2d edition, 1890.

leaving the surface condenser, and of similarly transferring heat from the next preceding step in the series to the next succeeding step in the heater, and thus proceeding in sequence, until the feed-water just about to enter the boiler should receive an accession of heat from the steam beginning its expansion and immediately after cut-off, and could this transfer be made so complete that, in the end, all the heat necessarily employed in heating the feed-water should be taken from the steam after cut-off in this manner, instead of all being used in the production of work of expansion, the approximation to the Carnot efficiency would become complete as the number of divisions should approximate infinity. In other words, this would be an ideal "regenerator system," and would exhibit maximum, Carnot, efficiency.

It is perhaps now possible to see why the use of prime steam, and of steam from intermediate receivers and from jackets, may prove advantageous and a gain in no sense paradoxical. This system would involve the loss of work of expansion, and also evade all expenditure by work of compression; the net result would be the transformation of heat transmuted into work wholly at the initial, maximum, temperature and pressure, and the rejection of all heat discharged from the system at all, at the minimum temperature and pressure of the cycle—the conditions of maximum possible efficiency as stated and illustrated by Carnot. This "grating arrangement" of feed-water heater would thus find practical use. Such a system will perhaps always prove impracticable in absolute perfection; but its partial and limited application has been found by experience to be practicable, and actually to give very sensible gains,* which fact will be presently seen to be illustrated in the case in hand.

The modification of the cycle in this manner, if it could be perfectly effected, would result in a gain of about 30 per cent.; the original and resultant cycles and efficiencies being as indicated in Tables I. and II., and the cycle diagrams taking the

* The first application of this principle, in actual construction, of which the writer has learned, was that of John Bourne, who, many years ago, constructed a marine engine with a "snifting valve" to open just before expansion was complete and exhaust began, to divert steam from the steam cylinder into a feed-water heater, thus to raise the temperature of the feed considerably above that of the condenser. The later method is that of Weir, of Kirkaldry, and of Nordberg.

customary shape in the case of the Rankine cycle, and approximating the form of a rectangle—having slight expansion and

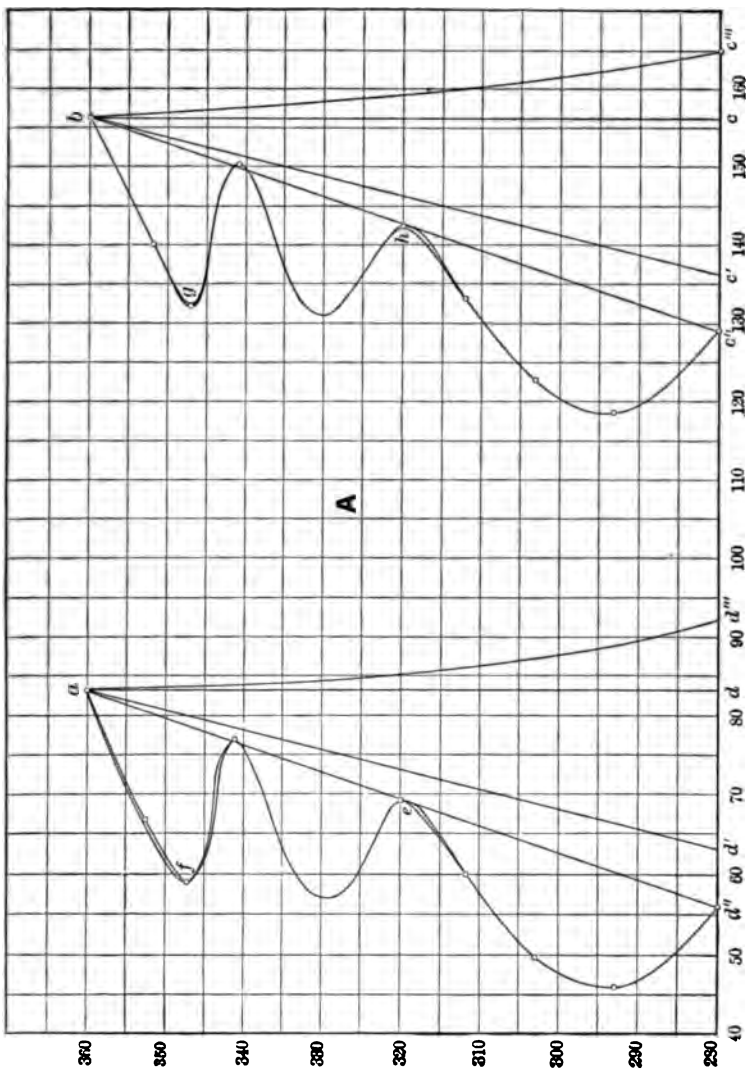


FIG. 21.—TEMPERATURE-ENTROPY DIAGRAM.

no compression lines—in the case of the Carnot equivalent above described.

In Fig. 21, let *A*, *abcd*, represent the temperature-entropy diagram of the perfect steam engine, the Carnot, cycle, and let *B*, Fig. 22, *abcd*, be the corresponding pressure-volume diagram of

a similarly perfect cycle. It is well recognized as characteristic of this cycle that the heat rejected from the system is all rejected at the minimum limit of temperature and pressure, as all the heat entering it is received at the maximum temperature and pressure, and thus that temperature is constant during all

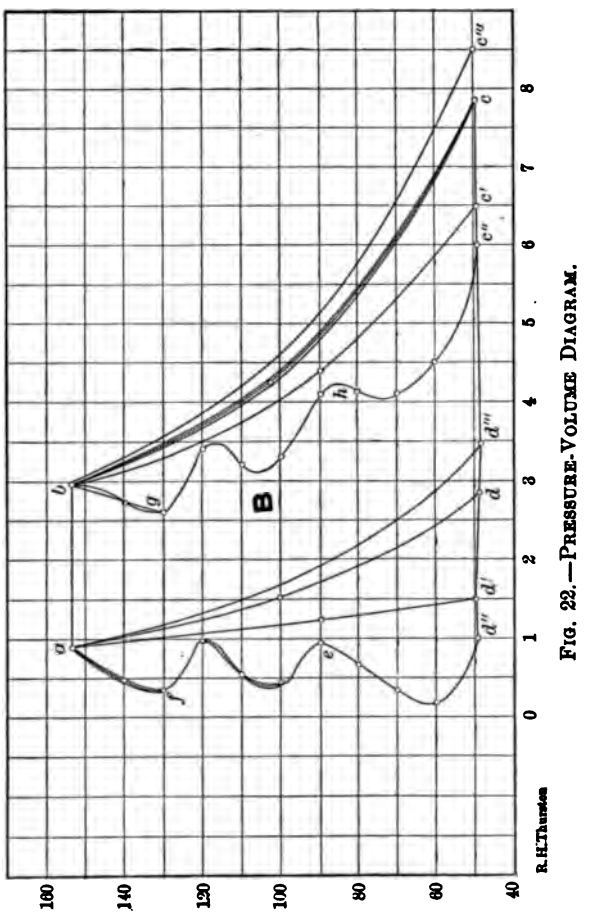


FIG. 22.—PRESSURE-VOLUME DIAGRAM.

change of entropy, while entropy is constant during all change of temperature. The pressure lines in *B* are of constant altitude, and the expansion and compression lines are adiabatic and are very nearly hyperbolic. It is further obvious that, the principle of Carnot being adhered to, and all heat being received at the maximum and all rejected at the minimum limits of tem-

perature, it is a matter of indifference by what process the drop from the maximum to the minimum is effected. It is evident that this change may be produced either by transforming heat into work, temporarily, during an expansion period, for later restoration during a compression period, as in the case of the Carnot operation, or by transferring heat from the working substance, storing it in a "regenerator system," and returning it to the working substance at the opposite side of the cycle. In other words, the limiting lines of these diagrams may be changed in any manner, as in the diagram *A*, from *ad* and *bc* to *ad'* and *bc'*, or to *ad''* and *bc''*, or to *ad'''* and *bc'''*, or as in *B*, from *ad* and *bc*, adiabatic expansion lines, to *ad'* and *bc'*, to *ad''* and *bc''*, or to *ad'''* and *bc'''*, even *abghc''d''ef; provided*, always, that the space inclosed in the cycle *A* remains unaltered; provided, in other words, that all horizontal elements of the temperature-entropy diagram remain of the same length as originally. Thus altered and thus limited, the efficiency of the system remains unchanged, and the new adjustment gives the exact thermodynamic equivalent, so far as efficiency is concerned, of the Carnot, or perfect engine, cycle.

The common Corliss engine cycle has as nearly as practicable an adiabatic expansion line but no compression, and is represented in *A* by *abcda''*, or by *abc'''da''*, and in *B* by *abcda''*, or by *abc'''da''*; heat in the last case being absorbed by the cylinder at the beginning, and given up to the steam toward the end of the stroke in the real engine. It is evident that if heat can be removed during the expansion period to be restored to the working fluid during the period of increasing pressure, thus converting the cycle from the usual form to more nearly the ideal, and, by cutting off the right-hand ends of the horizontal elements of the diagram, and lengthening in approximately similar degree the left-hand abscissas, the change will bring the cycle into closer accord with the prescription of Carnot. Further, if it should prove possible to reduce the pressure and temperature between maximum and minimum, by transferring heat from *bc* to the feed-water, so as to raise its temperature completely to that of the "prime steam," in that degree the Carnot system would be approximated. Could such an operation be made to produce the diagram *A*, *abc'd'a*, of which the area remains unchanged in this resultant departure from the standard perfect engine cycle, the outcome of this modified action of the engine

would be as close an approximation to the performance of the perfect engine as the practical conditions of structure and operation permit.

Thus it is seen that the supply of steam to the feed from the jackets and receivers, or even the expanding mass of working steam, may prove advantageous to the system, and this will be presently seen to be the reason, in part at least, and probably mainly, of the exceptional efficiency and economy of the apparatus about to be described. Could all the heat be drawn from the expanding steam that is required in the elevation of the feed-water temperature from its maximum, as produced by the economizer system, to that of the boiler steam, and in such manner as to make the expansion line, as well as the steam line, approximate the vertical on the indicator diagram, the efficiency of the perfect engine cycle would be very closely approximated. This arrangement can be conceived, was conceived by Cotterill, and various methods of practical employment may also be imagined; yet since it is necessary that each accession of heat by the feed must come from a point on the expansion line of similar temperature, most of them would involve an indefinite number of working cylinders and receivers, and it may be questioned whether this method can ever be made commercially practicable to a much greater extent than in the example to be here described, so far as the number of steps in the process is concerned. It is, however, fair to presume that improvement in detail may be effected. John Bourne showed the way into this path many years ago, and Cotterill exhibited the scientific theory of the method; the perfection of the Bourne process by the Cotterill theory seems now about to become a practical problem in the fields of construction and operation.

The problem of the designer of the engine to be described in this paper may now, perhaps, be seen to be that of substituting, as far as practicable, heat absorbed from the expansion side of the diagram for that drawn from the fuel at the boiler in the production of the line of rising pressures on the Corliss engine diagram. In so far as this is practicable, gain may be secured by thus approximating the conditions defining the ideal regenerator cycle, first described in detail, as applicable to the steam engine, by Cotterill.

The Ideal Rankine Non-conducting Engine, with 2 pounds back

pressure, and a terminal pressure on the expansion line of 7 pounds per square inch, should have an efficiency measured by a consumption of heat in British thermal units per horse-power per hour of about

$$H = 20{,}000 / log.\ p_1 \text{ (ideal)},$$

where p_1 is the steam pressure in pounds on the square inch.

The best records for the simple engine with dry and saturated steam, to date, appear to approximate

$$H = 36{,}000/log.\ p_1 \text{ (simple)};$$

those for the best compound engines similarly approach

$$H = 32{,}000/log.\ p \text{ (compound)};$$

those for the best class of triple-expansion engines give

$$H = 27{,}000/log.\ p_1 \text{ (triple)},$$

and those for the best class of quadruple-expansion engines attain approximately

$$H = 26{,}000/log.\ p_1.$$

The last figures indicate waste in the best real engines, aside from friction, of about 25 per cent. of the heat supplied; while those for the older form, the simple engine, show a loss of 50 per cent., nearly. The internal wastes are reduced nearly in proportion to the number of cylinders in series. Individual engines in either class may vary considerably from these figures; but an engine of either of the classes designated, when the machine is designed by a successful practitioner, may be fairly expected to approximate some such figures as the above. For steam per horse-power per hour the expressions will usually not differ greatly from those above given, on the assumption that with good feed-water heating systems the pound of steam conveys about 1,000 British thermal units to the engine, and the constants may thus be taken as those above given divided by that number. Either form of expression may be taken as a standard, and the performance of individual engines may be gauged by a comparison with one of these expressions.

The Wastes of our Best Engines may be to-day taken as usually not far from 20 per cent. thermal and 10 per cent. dynamic. At the beginning of the century they were, in Watt's best engines, about 60 per cent. thermal and from 15 to 20 per cent.

dynamic, as shown on the diagram Fig. 23, *A*. The progress of the century is seen to have been mainly in the reduction of the internal thermal wastes. The progress of to-day is mainly in improvement of the thermodynamic efficiency by increasing range of temperatures worked through, and by improving the cycle in the direction of approximation more nearly to Carnot's ideal. Its outcome at the end of the century is seen to be indicated by the curve *B*, as probably a duty of about 160,000,000 foot-pounds per pound of pure carbon burned in the furnace of the best contemporary form of steam boiler; its efficiency being

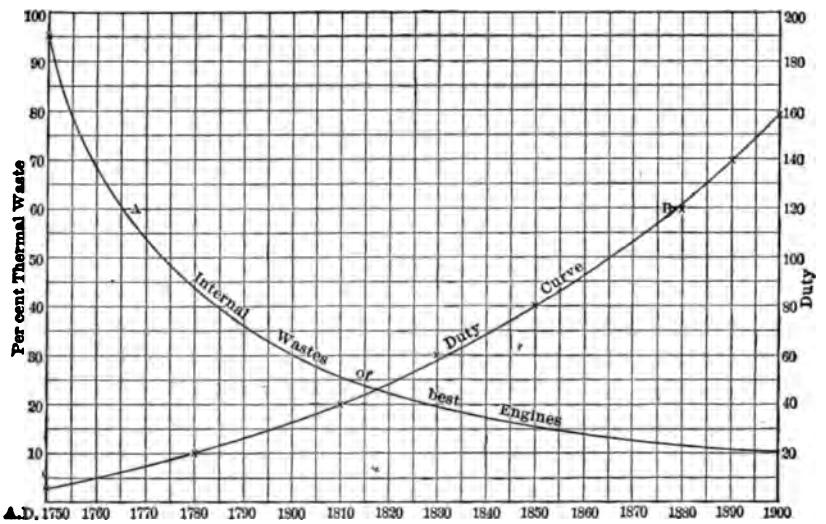


FIG. 23.—PROGRESS IN STEAM ENGINE EFFICIENCY.

American Bank Note Co., N. Y.

about 80 per cent. This diagram was constructed some years ago, and is therefore in the nature of a prophecy.*

It will be particularly interesting to observe, as time goes on, when and where the curve changes its curvature and assumes the ultimately inevitable concavity, indicating approach to the practical limit of gain by approximation to the ideal.

The Record of Actual Performance to date, as accurately as it has been practicable to secure it, is the following, and the accuracy of the diagram may be taken as within the usual limits of errors of observation and computation. It is reproduced above

* No. DCCX., vol. xviii., 1896, *Trans. A. S. M. E.* "Manual Steam Engine," vol. i., sec. 26, p. 81, chap. i.

from an earlier paper for convenience of reference and also as showing the fact that the progress anticipated in its original construction, some years before its first publication, has been curiously and very accurately following the prophetic line of the last diagram. The points of observation on the curve are the highest probably accurate duties noted, decade by decade, from the time of Newcomen and Watt up to and inclusive of 1890.* The reported duties are reduced to a conventional standard—in millions of foot-pounds per 100 pounds of good coal—as nearly as practicable, and inscribed at the right, the corresponding wastes on the left-hand scale. On the assumed basis, the perfect engine with efficiency unity—*i. e.*, back-pressure zero—were such an engine possible, would give a duty of about 1,200,000,000. Assuming a practicable maximum of thermodynamic efficiency of 30 per cent., the maximum attainable duty of the otherwise perfect engine would be 360,000,000, above double the highest yet reached.

Taking the pound of fuel as representing in ordinary boiler practice 10,000 British thermal units delivered at the engine, the standard here assumed and taken as the basis of construction of the diagram (Fig. 4) corresponds to the now common basis of duty measurement, the work performed per million British thermal units supplied the engine, that standard which is accepted as the basis of the duty computations to be here presently given.

The "World's Records" to 1895, as collated by Unwin, are given in Table IV., with additions to date, 1899, by the writer, marked by double asterisks, and with the addition of columns showing the corresponding "duties," and the quantities of heat, as nearly as can be ascertained, for these duties, in British thermal units per indicated horse-power per hour.† This reduction is necessary where steam pressures and particularly temperatures of feed-water are widely variable, and where, as in the case of the Schmidt engine, the steam is superheated, and thus charged with considerable more heat per pound than in the case of saturated or nearly saturated steam. The true comparison

* "Promise and Potency of High-Pressure Steam," *Trans. A. S. M. E.*, December, 1896, vol. xviii. "Manual Steam Engine," fourth edition, p. 81.

† Where these quantities are unknown, they are assumed at 1,100 British thermal units per pound of steam, and friction of engine 10 per cent. ; 1,782,000 foot-pounds being delivered per *indicated* horse-power per hour.

lies between the quantities of heat from the furnaces, rather than quantities of steam from boilers; although, in ordinary practice, the differences observed in the two systems of measurement are usually unimportant; the quantity of steam, per horse-power and per hour, for efficiency unity, being almost invariably about 2.3 pounds for the condensing and 2.5 pounds for the non-condensing engine.

TABLE IV.

MINIMUM STEAM CONSUMPTION.—1899.

	I. H. P.	Steam Pressure.	Speed of Piston. Feet Per Minute.	Per I. H. P. Per Hour. Pounds Limited.	B. T. U.	Foot-Pounds Duty Per 1,000,000 B. T. U.
Simple Engine.						
Sulzer.....	284	87	372	18.4	20,250	88,000,000
Corliss.....	137	62	...	17.5	19,250	92,630,000
Compound.						
Dujardin.....	548	90	570	13.46	14,800	120,400,000
Sulzer.....	247	85	493	13.35	14,700	121,100,000
Wheelock.....	590	160	612	12.84	14,100	126,400,000
McIntosh & Seymour **.....	1,076	125	800	12.76	13,000	137,000,000
Leavitt.....	643	135	371	12.16	13,400	133,000,000
Triple Expansion.						
Sulzer.....	615	141	516	11.85	13,000	137,000,000
Reynolds.....	574	120	203	11.68	13,056	140,817,000
Leavitt **.....	576	185	240	11.22	12,242	141,855,000
Snow **..... ...	773	156	215	11.26	.....	150,100,000
Quadruple.						
Hall & Treat **..	16	300 400 500	220	10.80 9.65 9.75	13,500	132,000,000
Nordberg **....	712	200	250	12.26	11,158	162,948,824

The Best Graphical Method of exhibiting the "promise and potency" of improved methods of use of steam of increasing pressure is perhaps that of graphical representation in a manner already illustrated by the writer in other papers. Making the coördinates of our curves of efficiency the steam pressures, and the costs of power in British thermal units per horse-power per hour, we may construct the following diagram of curves of efficiency (Fig. 24) of this character, and upon it may inscribe the records, to date, of our most famous engines, thus:

The best work of American steam pumping engines includes that of those in operation at Milwaukee, Wis., at Chestnut Hill,

Mass., at Detroit, Mich., at Buffalo, N. Y., and at Indianapolis, Ind., all triple expansion, and the Pittsburg quadruple-expansion engine here added to the list. The performance of the other engines, tabulated by Mr. George H. Barrus, and reported to the New England Water-Works Association, December 14, 1898, may be read from the statement, Table V. It will be seen that the duty attained by these machines ranges from 130,000,000 to 150,000,000 of foot-pounds per million British thermal units supplied, while the expenditure of dry steam per indicated horse-

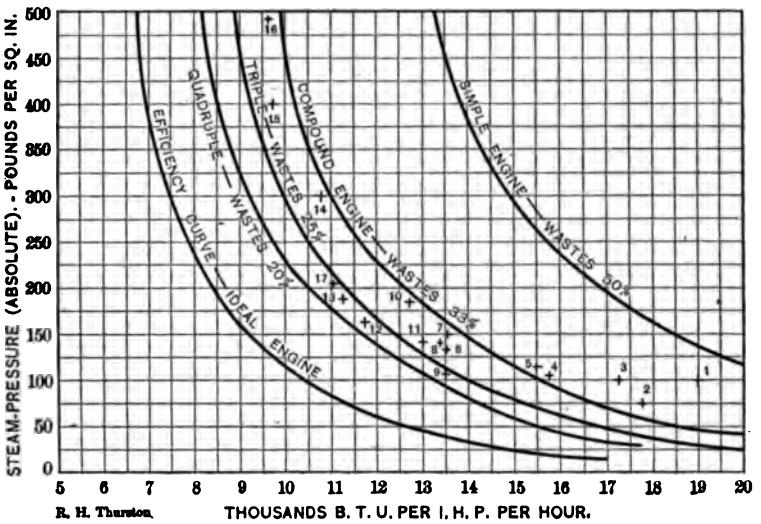


FIG. 24.—PERFORMANCE OF BEST TYPES OF ENGINE.

1. Simple; 2. Simple; 3. Compound, 3 to 1; 4. Compound, 3 to 1; 5. Compound, 7 to 1; 6. Compound, 7 to 1; 7. Triple; 8. Triple; 9. Compound; 10. Compound, 7 to 1; 11. Triple; 12. Triple; 13. Compound; 14, 15, 16. Quadruple; 17. Quadruple.

power per hour ranges from 11.22 to 12.52, the steam pressures at the engine varying from 121 to 176 pounds. All are large engines, and develop from 574 to 1,185 indicated horse-power. All have ratios of total expansion closely approaching 20, none exceeding 24. All, with the exception of the second on the list, have a piston speed not far from 200 feet per minute; the exception attaining the remarkable figure—for a pumping engine—of 600 feet. In the first three cases, the friction is the usual minimum of about 10 per cent., while in the last two cases it is reduced to the remarkable values 5.1 and 4.6, if no error has arisen. The cylinder and jacket and receiver condensation

TABLE V.—PUMPING ENGINES.

1. Name of designer or builder	E. P. Allis Co.	E. D. Leavitt, Jr.	E. P. Allis Co.	Lake Erie Eng. Works.	Snow Steam Pump Works.
2. Locality	Milwaukee, Wis.	Chestnut Hill, Mass.	Detroit, Mich.	Buffalo, N. Y.	Indianapolis, Ind.
3. Type	Trip. Ex.	Trip. Ex.	Trip. Ex.	Trip. Ex.	Trip. Ex.
4. Extent of jacketing.	Barrels and receivers.	Barrels, heads, and receivers.	Barrels and receivers.	Barrels and receivers.	Barrels, heads, and receivers.
5. Name of expert conducting test	Prof. R. C. Carpenter.	Prof. E. F. Miller.	Geo. H. Barrus.	Geo. H. Barrus and Newcomb Carlton.	Prof. W. F. M. Goss.
6. Capacity—million gals. in 24 hours	18.	20.	24.	30.	20.
7. Size of steam cylinders, in.	28, 48, 74 × 60	137.7, 24.37, 39 × 72	28, 48, 74 × 60	37, 63, 94 × 60	29, 52, 80 × 60
8. Size of water plungers, in.	32 × 60	Double acting 17.5 × 48	36 × 60	42 × 60	33 × 60
9. Total head, lbs.	70.4	59.4	53.4	86.1	88.7
10. Piston speed feet per minute.	203.1	607.	209.9	207.7	214.6
11. Ratio of volume of L. P. cylinder to volume of H. P. cylinder	7.1	8.3	7.1	6.5	7.7
12. Pressure near throttle (above atmosphere), lbs.	121.4	175.7	125.2	167.1	155.6
13. Cut-off pressure (above atmosphere), lbs.	118.6	151.5	119.4	152.2	153.
14. Release pressure, L. P. cylinder (above zero), lbs.	5.3	6.9	5.8	7.4	6.4
15. Back pressure, L. P. cylinder (above zero), lbs.	1.6	1.5	2.8	2.2	2.5
16. Cut-off, H. P. cylinder	.337	.384	.338	.323	.315
17. Clearance, H. P. cylinder	.014	.015	.014	.014	.018
18. Ratio of expansion	20.4	21.	20.3	19.6	23.8
19. Ratio of expansion referred to pressure near throttle	20.8	23.9	21.2	21.3	24.3
20. Absolute pressure near throttle ÷ ratio of expansion, lbs.	6.6	9.1	6.9	9.3	6.8
21. Indicated horse-power, I. H. P.	573.9	575.7	573.7	1,185.5	775.5
22. Friction, per cent.	9.2	10.5	10.2	5.1	4.6
23. Dry steam per I. H. P. per hour, including jacket and reheater steam, lbs.	11.68	11.22	12.52	12.39	11.26
24. Per cent. of steam condensed in jackets and reheaters, per cent.	9.2	17.1	12.7	13.7	10.5 (est.)
25. Dry steam per I. H. P. per hour, exclusive of steam used in jackets and reheaters, lbs.	10.61	9.3	10.93	10.7	10.08(est.)
26. Steam accounted for by indicator, H. P. cylinder cut-off, lbs.	9.05*	8.5*	9.5	9.1	8.7*
27. Steam accounted for by indicator, L. P. cylinder cut-off, lbs.	8.7*	9.6*	9.5	9.7	8.7*
28. Steam accounted for by indicator, L. P. cylinder release, lbs.	9.04*	9.1*	9.9	9.7	9.8*
29. Cylinder condensation and leakage, including jacket and reheater condensation, at cut-off, H. P. cylinder	.225	.242	.241	.266	.227
30. Mean effective pressure referred to L. P. cylinder, lbs.	21.77	26.36	21.03	27.19	23.65
31. Theoretical mean effective pressure referred to pressure near throttle valve and ratio of expansion at same point	26.42	33.23	26.76	34.63	29.66
32. Line 30 ÷ line 31, or "diagram factor"	.824	.794	.792	.786	.797
33. Duty based on 1,000,000 heat units, expressed in million foot-pounds	137.	141.9	129.7	135.4	150.1
34. Duty based on 1,000 lbs. of dry steam, expressed in million foot-pounds	154.0	154.0	142.4	152.	167.8

* Calculated by G. H. B.

amounts to from 22.5 per cent. in the first, to 26.6 per cent. in the fourth, of which from about one-half to two-thirds is found in the jackets and receivers, the smaller value being the more usual.

The differences in steam pressure and in method of employing heaters and other heat-saving accessories in such cases are such as to make comparison, as will be shown more clearly later, a somewhat uncertain matter; but the reduction of all statements of duty to a basis of 1,000,000 thermal units as the unit of expenditure of heat at the point of supply eliminates all such differences except that of steam pressures, and it is then easy, as also shown hereafter, to secure a true comparison where seeking to compare values of engine type.

In the appended Table VII., collated by Donkin, is the statement of the essential data of a large number of engine trials, exhibiting the progress made to its data of the best designers and builders on both sides the Atlantic.

The Nordberg Engine about to be described is a four-cylinder, quadruple-expansion machine, built by the Nordberg Manufacturing Co. from designs of Mr. B. V. Nordberg, and set up at a station of the Pennsylvania Water Co., near Pittsburg, Pa., to operate under 200 pounds steam pressure and under a head of about 600 feet between well and reservoir; delivering its water through a rising main of about one mile in length and of 30-inch pipe, taking it from the Allegheny River through a suction pipe 600 feet long and 24 inches in diameter. The water pressure at the pumps is thus about 275 pounds, normally. The form of the engine is seen in the accompanying reduced illustrations from photographs taken in the erecting shop (Figs. 20, 25, 26, and 27).

The capacity of this engine is six millions (6,000,000) U. S. gallons per twenty-four hours against a head of 620 feet. The engine is designed to pump water from the Allegheny River, in which the variation of the water-level is very great, nearly 40 feet between the highest floodmark and extreme low water.

At the Wildwood pumping station there was a well, 38 feet diameter, which was to be utilized for the new engine, and for two more engines of the same type. It was thus necessary to design an engine to go into minimum space.

The engine (Figs. 20, 25, 26, 27, 32, 33, and 34,), self-contained, rests on a large base-plate, which also serves as a suction

air-chamber for the pump. This base-plate rests directly on the country rock, there being no artificial foundation. The

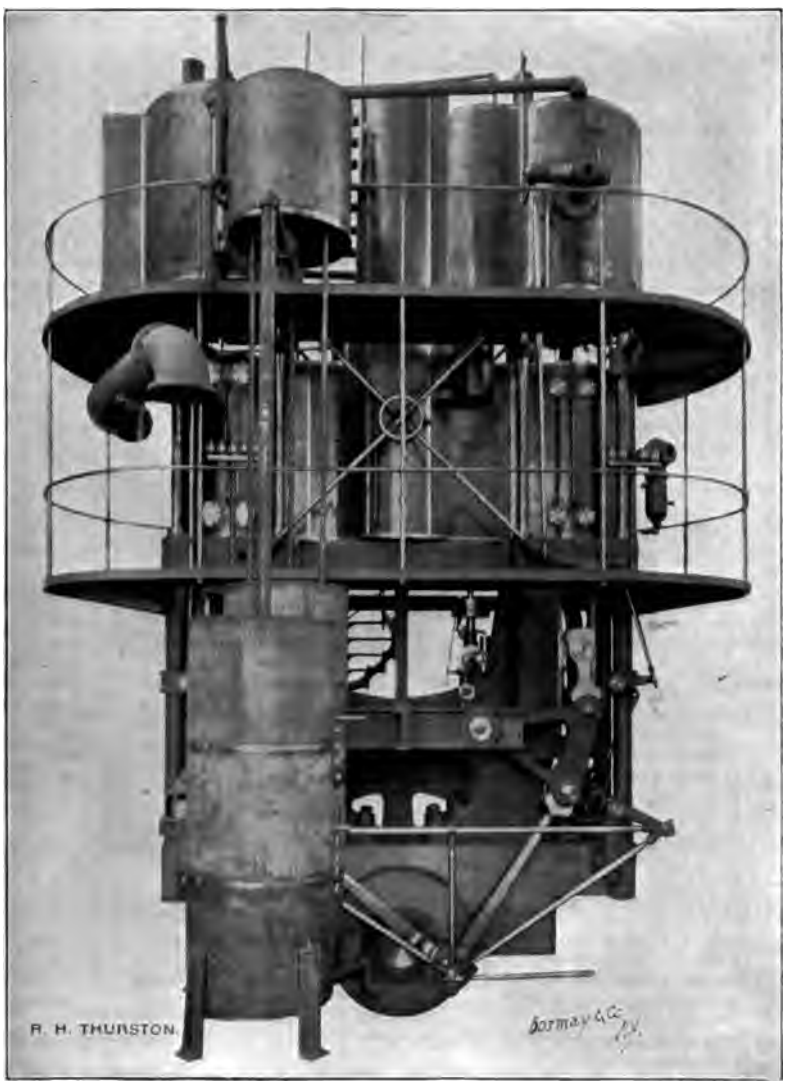


FIG. 25.—REAR OF ENGINE.

water-inlet tunnel, which is 6 feet in diameter, is led under the centre of the well, and from there a suction pipe leads to the middle of the base-plate, a valve being arranged on its top by

which the water can be shut off, and a safety valve is arranged on the top of the base-plate to guard against straining this plate in case the pump valves should leak when the water is shut off from the suction; in which case there would be danger of getting the full hydraulic pressure on the base.

The pumps are double acting with outside packed plungers, and rest on the base-plate. The detailed drawings (Figs. 32 and 34), show the design of these pumps. Each pump is made in two castings, all four valves being arranged directly in line, one above the other, the plungers being located on one side of the valve chambers. The valves are of rubber, working on brass seats, and arranged in polygonal cages, by which arrangement a minimum diameter of valve chamber is obtained. The drawing shows how the suction and discharge chambers are connected.

In order to guard against breakage of pumps, which in the neighborhood of Pittsburg is quite common, due to the high water pressure and other conditions, the pulsating chambers of the pumps are enveloped in steel casings. The section shows these steel jackets, and the method by which they are fastened to the pumps. It will be seen that there are bolts passing through the pulsating chambers, which serve as anchorage for the plates, or jackets, in question. The jackets are made in halves, and the joint made in the plane passing through the centre of the cylinders. Strong set-screws placed in the jackets bear upon the ribs of the pump casting underneath, thus relieving this from the strain due to water pressure. The arrangement is thought to be absolutely safe against breakages.

It is particularly important that the pumps should be very safe in this case, as the engine rests on the pump, and the valve-chamber castings of the pumps are part of the engine framing. It will be seen that the valve chambers are extended on top to receive the engine bedplate, in which is the main bearing, and which supports the engine frame.

A notable and unique feature of this particular engine is that the engine framing is placed in the centre of the machine, extending from under the centre of the cylinders, downward, with the running parts arranged outside of the framing. There is only one main bearing, extending clear across the engine bedplate. There is a crank-disk on each side of this bearing, on the outside of which are clamped the two flywheels. On each crank-disk is a pin; the two pins being exactly in line.

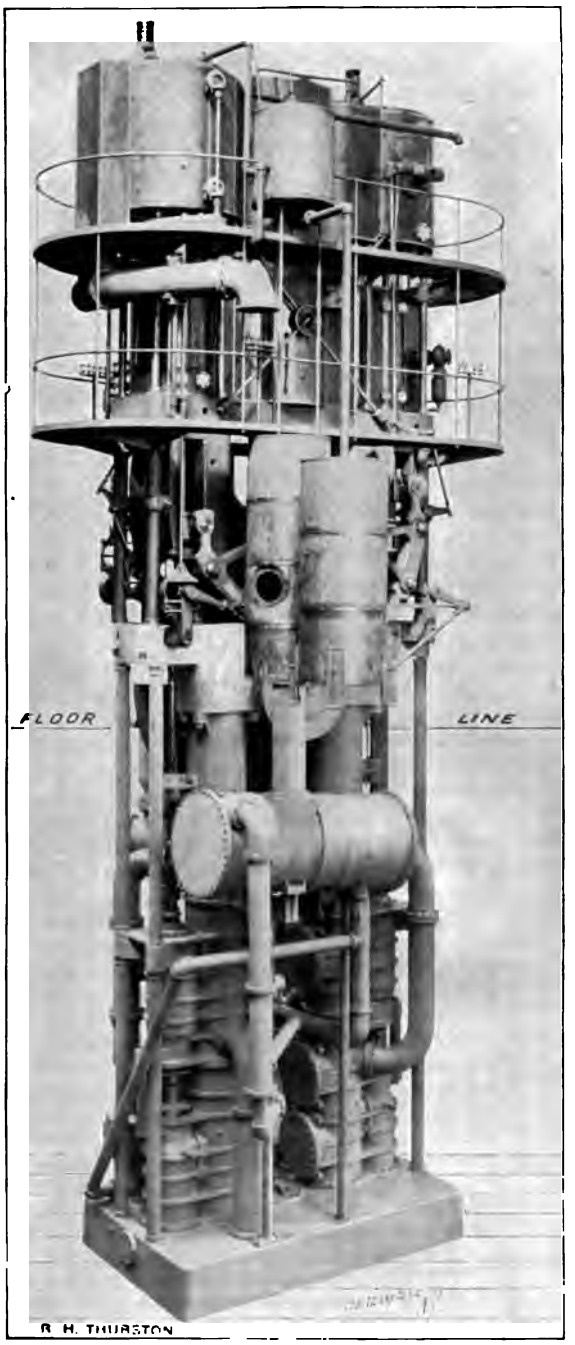


FIG. 26.—PUMPS AND HEATER SYSTEM.

The plunger rods are directly connected to the steam pistons. At the upper end of these rod connections, and immediately below the steam cylinders, are cross-heads keyed to the rods; which cross-heads project sideways outside of the engine frame, and are here formed into pins, which connect, by means of short links, to corresponding pins of the rockers. There are thus four rockers; two on each side of the engine, one driven from each end of cross-heads. Directly in line with the cross-head-pin and its corresponding pin on the rocker, this rocker is provided with a second pin which takes the main connecting rod and connects to the crank-pin. These pins are located in such a position as to bring one side of the engine and one pump on the dead centre, while the other side of the engine, with the other pump, is in the middle of its stroke.

Each side of the engine carries two cylinders placed tandem; the high-pressure side the cylinders Nos. 1 and 3, and the low-pressure side the cylinders Nos. 2 and 4.

The slides in the cross-head are formed in the engine framing.

The pins on which the rockers are supported are fastened, stationary, in the engine framing, the bearing being formed in the rocker itself.

It will be seen from the above that there are two connecting rods attached to each crank-pin; the two connecting rods are in the same plane, and thus one is forked at the crank-pin end, while the other one is single.

The engine frame proper is located inside the piston-rods. In order to get a proper support outside the piston-rods there are on each side two columns extending from the base-plate at the bottom of the machine clear up to the low-pressure cylinders, each column being carried through in an unbroken line. These columns are of cast iron with a steel tension rod in the centre up to the top of the engine framing. From that point upward they are extended by means of polished steel rods.

Between the engine frame and the low-pressure cylinders are a second set of polished steel columns on the inside of the centre lines of the cylinders, and spaced equally with the outside columns; thus the low-pressure cylinders are entirely independent of the high-pressure cylinders, resting on columns of their own. A cross bracing is arranged to give the low-pressure cylinders additional stability.

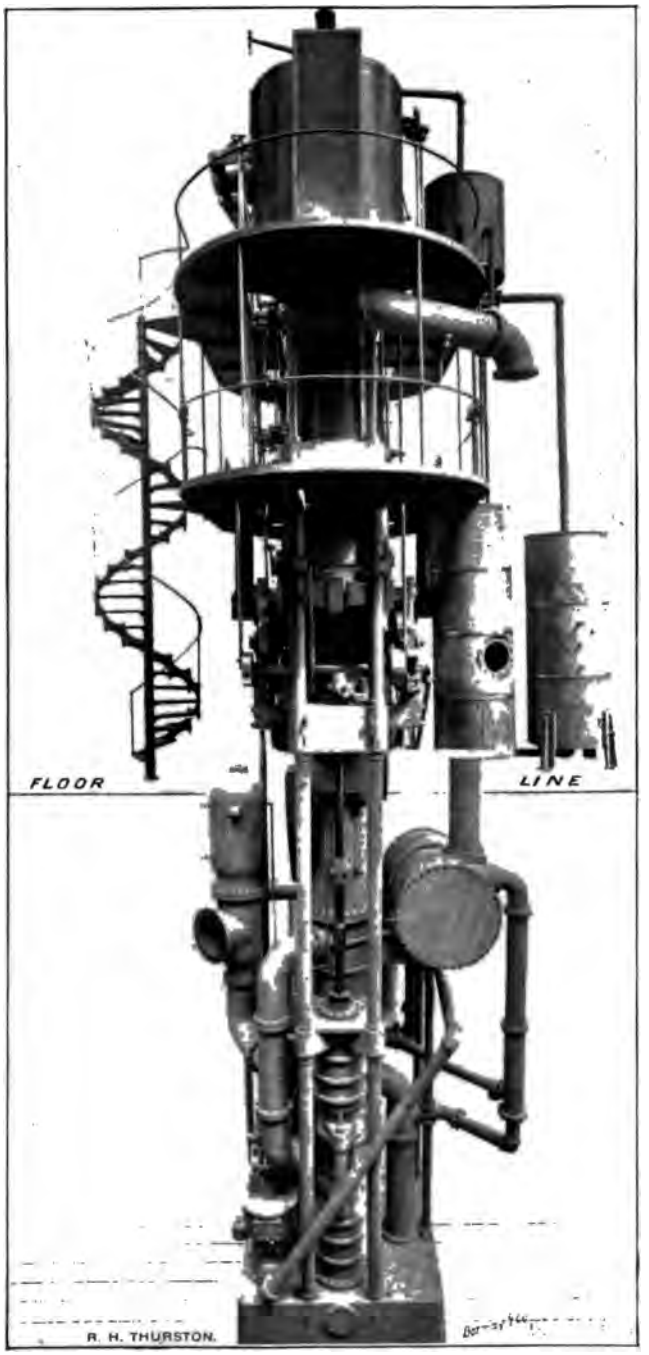


FIG. 27.—PUMPS AND HEATERS.

At the centre of rockers the engine is held to the side of the pit by means of light bracing.

The receivers are provided with tubular reheaters, as shown on the detailed drawing. These receivers are located between the cylinders, and mounted one upon another in such a manner as to reduce to a minimum the losses caused by radiation.

In order to reduce to a minimum the heat-conduction losses, the high-pressure cylinders are provided with a number of projections, at the bottom ends, which rest upon the framing, and leave quite a space between the body of the cylinder heads and the frame, which is filled out with non-conducting material; the only surface in contact with the cylinder and frame being the small surface of these projections, or bosses.

All cylinders are steam jacketed on the barrels only, the high-pressure cylinders being provided with separate liners; the low-pressure cylinders having the jackets formed in one casting with the cylinders. The valve gear is of the Corliss type, with the exception of the No. 4 cylinder valves, and the exhaust valve gear on No. 3 cylinder, in which single-beat poppet valves are used in order to reduce clearance to a minimum. The cut-off is variable on all cylinders, except on No. 4; the high-pressure cut-off being under control of a centrifugal governor. As the cylinder ratio between No. 2 and No. 1 cylinder is comparatively small, and a low degree of expansion is carried in the high-pressure cylinders, a special valve gear had to be used in these cylinders, by which steam can be cut off after half-stroke. The ratio between No. 3 and No. 2 cylinders is so great that steam can be cut off before half-stroke, and an ordinary Corliss gear was used in this cylinder. The ratio between No. 4 and No. 3 is small; steam in No. 4 had to be cut off at about three-quarters, thus requiring no special cut-off mechanism, or trip releasing gear.

The valves are operated from two revolving lay-shafts, one on each side of the machine. With the construction of the crank-shaft it was not easy to arrange eccentrics on this shaft, from which to operate the valve gears. A rotating gear, as illustrated in the drawing marked "Feed Pump and Valve Gear Drive," was therefore used to transmit the rotation of the crank-shaft to the lay-shafts. From one of the lay-shafts the governor is driven by a belt.

A surface-condenser was used in connection with this engine.

This condenser had to be located so high that at times of low water the main pump could not be depended on for circulation unless the full water pressure was carried on the condensers, which would not be advisable. A circulating pump was therefore used which takes the water from the suction base and elevates it into the condenser. The circulating water from the condenser is returned to the suction through two branches, one entering each pump. It was thought best to do this instead of letting all the water come back to one point; although there might not be much advantage in doing it. The end view and section *DD* of the machine shows this pipe. The surface condenser is very much like those used in marine practice. The water passes through the condenser three times, entering at the bottom and leaving at the top. It is the practice of the designer to incline all surface condensers, as the water of condensation has a better chance to run off. The tubes are three-quarter-inch in diameter, held in place by vulcanized fibre bushings.

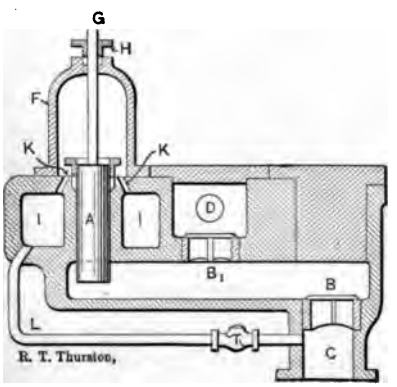


FIG. 28.—FEED-PUMP.

Mr. George H. Corliss probably originated the vertical air pump without foot valve; this is the type of air pump used with the Wildwood engine. The discharge from the air pump runs into a tank, from which it is elevated by means of a separate pump into a high-level tank.

The circulating pump, the air pump, and the tank pump are all operated by means of a lever-and-rod connection from the crank-shaft of the engine, as shown in side elevation of the engine.

The pumps used with the heaters require special description. All builders have found it difficult to get a pump for hot water, and in this case a special design was made to handle water of a temperature above 300 degrees Fahr. The sketch (Fig. 27) shows the principle of the feed pumps, as designed, which pumps have given perfect satisfaction.

Fig. 28 shows the method of construction. *A* is the plunger, *BB* the suction and discharge valves, *C* the suction nozzle, and

D the discharge nozzle. The pump is single acting. A hood *F* is placed above the plunger *A*, the plunger rod *C* projecting through the upper end of the hood, in which is formed a stuffing-box *H*. An annular chamber *I* is formed around the main stuffing-box *J*, which communicates with the suction nozzle by a pipe connection *L* and a check valve, which opens when the pressure in space *I* exceeds the pressure in suction pipe. The main stuffing-box is packed with duck-packing, the stuffing-box *H* with metallic piston-rod packing. The pressure in the suction pipe *C* is about the same as in the receivers by which the different heaters are supplied with steam. The leakage through the packing in the stuffing-box *J* is caught in the space inside of the hood *F*, and the water runs thence through openings *V* into annulus *I*. The steam fills the space *E* inside of the hood, and stuffing-box *H* is thus never in contact with water, but with steam. Whenever the pressure in space *E* and in annulus *I* exceeds the pressure in suction pipe *C*, the check valve opens and discharges the water into the suction pipe. By virtue of this arrangement the pressure in *E* and *I* is always equal to the suction pressure.

Leading Dimensions of Engine:

No. 1. Cylinder	19½ inches.
No. 2. Cylinder	29½ "
No. 3. Cylinder	49½ "
No. 4. Cylinder	57½ "
Plungers	14½ "
Stroke of steam pistons and plungers	42 "
Main bearing	18 by 37½ "
Crank-pins	7½ by 12½ "
Cross-head pins	6 inches diameter by 5 inches long.
Pins in rockers	6 by 5 inches.
Main trunnion for rockers	9½ by 22 "
Low-pressure piston-rods	3⅝ inches diameter.
High-pressure piston-rods	4½ " "
Pump rods	4½ " "
Feed pumps. Single acting	6 inches diameter by 8 inches stroke.
Air pump. " "	20 " " by 14½ " "
Circulating pump differential 15⅝ bucket	10½ plunger by 34½ " "
Tank pump	5 inches by 9½ single acting.
Reheating surface; 1st receiver	139 square feet.
2d "	139 " "
3d "	139 " "
Condenser surface	1,500 " "
Suction pipe	24 inches diameter.
Discharge pipe	24 " "

This contract thus presented an unusually interesting and exacting problem in design. It was required to provide for three distinct machines in a single pit, which was but 38 feet in diameter, and this compelled the reduction of the diameter of the steam cylinder to a minimum, and the adoption of as high a piston speed as was safe. This accounts, in part, for the fact that the ratio of expansion was made less than is often observed in engines of this class, and it is thought by the designer that the results do not represent the highest duty to be expected of quadruple-expansion engines of this type, although the peculiar cycle adopted makes this ratio a matter of less importance.

The System of Regenerators employed (Fig. 29) was novel, and had not been before constructed by the designer; his idea being, in this matter, to secure such a system as would permit the economical use of the highest steam pressures that may prove safe in any case, returning the feed-water to the boiler at very nearly the temperature of the steam itself. Such attempts as had been previously made by him in earlier engines, to approximate this condition, had, however, proved very satisfactory, as may be seen by consultation of the reports of Chief Engineer Perry, U. S. N., on the U Street engine at Washington, D. C., published in London *Engineering*, and that of Prof. M. E. Cooley on the Grand Rapids engine by the same builders. These were triple-expansion engines. In the trials of all engines of this type it is evident that the necessary interruption of the heat cycle in the measurement of the feed-water must involve a loss of efficiency, of which loss only estimates can be made; although it should usually be possible to secure a very close approximation.

The Trials were made as routine work of the Department of Experimental Engineering of Sibley College, Cornell University, and were under the direct charge of Prof. R. C. Carpenter, who was assisted by Prof. J. H. Barr of Sibley College; by Prof. A. W. Richter of the University of Wisconsin (at the time engaged in graduate work as a candidate for the Master's degree in Sibley College); by Messrs. J. W. Prince, W. R. Miller, and F. M. Case, who sought data for a formal discussion of the case in their own work, and also by Messrs. E. F. Scattergood, A. Bruckner, B. S. Lanphear, W. J. Fullerton, and J. Seix, trained observers, and candidates for advanced degrees also, and by Messrs. S. D. Bullock, W. Ransom, and C. C. West of Sibley College. The Penn-

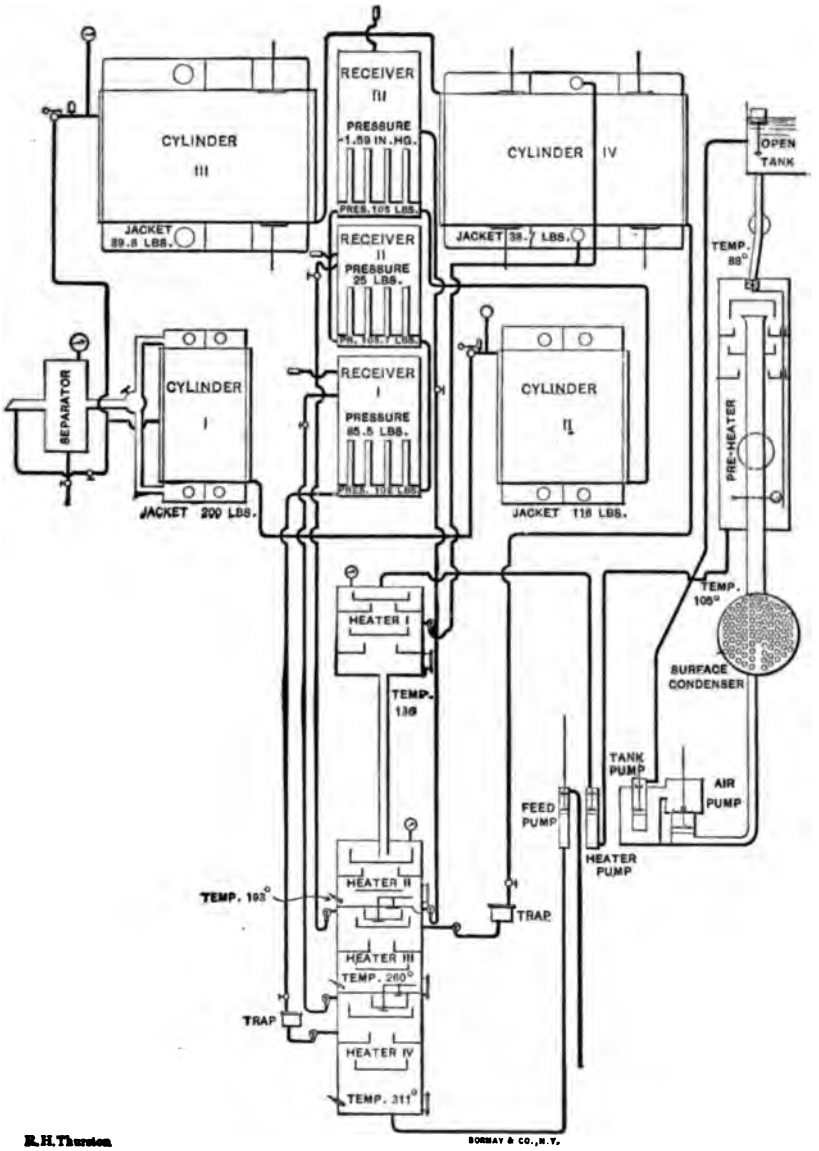


FIG. 29.

STEAM CONNECTIONS, HOT-WATER RETURNS and HEATERS

sylvania Water Company and the builders were represented throughout by their officers, and their observers checked all data.

The Duty Trial was made 36 hours in length. It had been intended to make it 48 hours, but this proved impracticable in consequence of the blowing out of a gasket on the feed-pipe, which interrupted the work. A trial of 6½ hours length was made without heaters, and later a run of 7 hours to determine the heat distribution. Two observers and duplicate observations were provided for in securing each essential datum. In this series of trials the duty was found to be somewhat less than had been anticipated by the designer, who attributed the difference between the results of his own preliminary trials and those of these official tests to imperfection in the action of the heaters. It was also discovered that the feed system had thrown some extra duty upon the pumps in consequence of the return of a part of the feed to the pumps by overflow after its discharge into the feed reservoir. The difference between weir measurements and plunger displacement was 0.8 of one per cent. of the plunger displacement.

The Duty reported was:

Per 1,000,000 British thermal units....162,948,824 foot-pounds.
Per 1,000 pounds dry steam.....150,254,138 "

The power developed was 712 indicated horse-power; the capacity, 6,225,052 gallons per 24 hours against a head of 602.7 feet. The weight of dry steam per indicated horse-power per hour was 12.26 pounds, which comparatively high figure is accounted for by the transfer of steam from the reheaters to the feed system, and by the small amount of heat absorbed per pound, where the feed-water is heated, as here, to 311 degrees Fahr. Heaters thus relatively increase water rates.

The heat expended amounted to 185.96 British thermal units per indicated horse-power per minute, 11,158 per hour, which figures and those for duty on the heat unit, the true, basis, are about 10 per cent. better than the previous best record. They establish a new *World's Record* for the steam engine.

A Trial made Without Heaters shows well the influence of steam pressure without special gain by feed-water heating. It gave a duty—

Per 1,000,000 British thermal units.....147,525,000 foot-pounds.
Per 1,000 pounds dry steam .....159,824,700 "

and the weight of the dry steam per indicated horse-power per hour was 11.4 pounds, showing clearly that the system of heating the feed-water is to be credited with the exceptional economy of the machine and its unexampled duty, raising the world's record from about 150,000,000 to about 163,000,000. The gain is not thus accounted for by simple increase of steam pressure; which gain would have been expected to be about one-third as great as that observed in this case, other things equal; nor is it to be attributed to the adoption of the quadruple-expansion, rather than a triple-expansion, cycle. It comes principally from the improved thermodynamic cycle.

The Heat Distribution of this engine is best shown by the use of the "Sankey Diagram," of which a reproduction, for this case, is given in Fig. 30. The heat supplied by the boilers, reckoned at 100 per cent., meets at *A* 30.7 per cent. of its own amount returned from the feed-heating system, distributes 15.6 per cent. to the jackets, and the balance to steam cylinder I. Transformed energy passes out of the system at *C* as work, of which less than 7 per cent. is lost as friction and is reconverted into heat and dissipated. Seventy-five per cent. is sent, at *D*, into the condenser, and the curious system of heating and of adheating feed-water uses a part of this, and much more, from the various jackets and receivers, in a manner readily traced on the diagram, so as to produce, in some degree, that transfer of heat from the expansion to the compression side of the type diagram which has been already described as the ideal substitute of Cotterill for the Stirling equivalent of the Carnot system, and as indicated in the description, just given, of the action of the engine. The heat is thus gained by the feed at increasing temperatures throughout. This diagram was prepared by Mr. Prince.

The Details of Dimensions and the data and computed quantities are given herewith, as secured by the observers already named, supervised by Professor Carpenter, who independently computed all essential data, and saw checked by skilled computers every important figure, and often by a system of repeated checks.

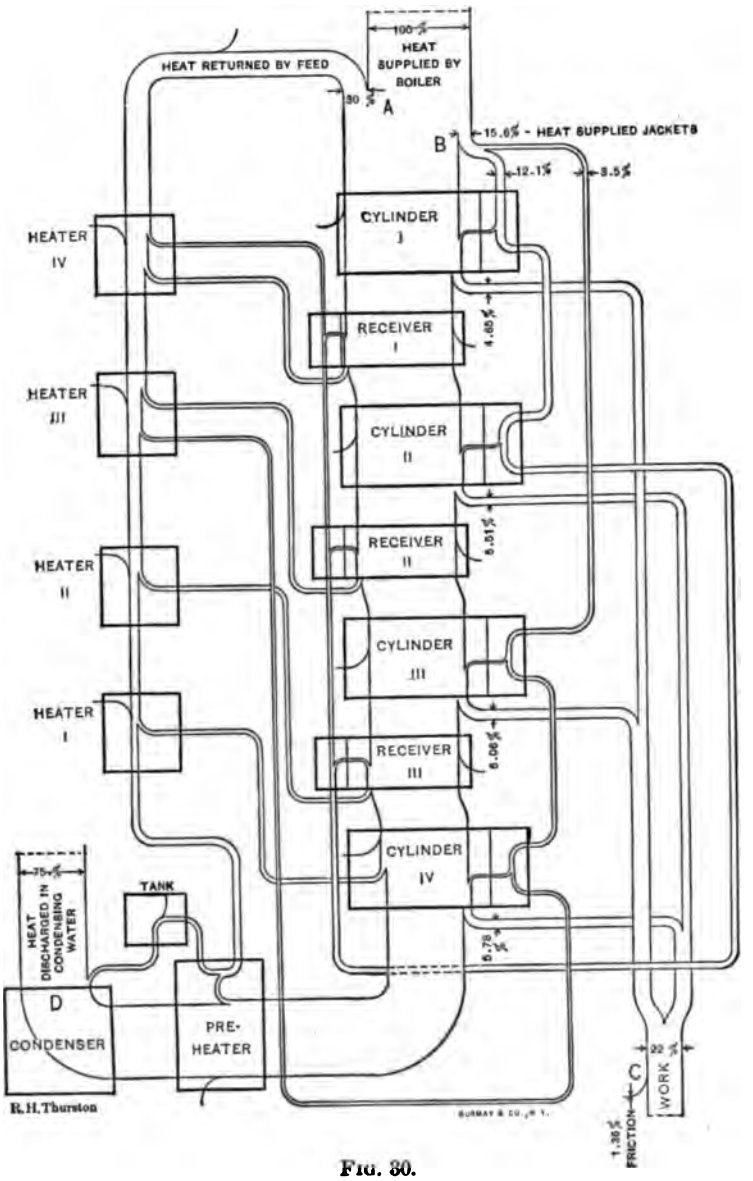


Fig. 30.

HEAT DISTRIBUTION

of the

NORDBERG PUMPING ENGINE

at

WILDWOOD, PA.

J.W.P.

TABLE VI.

DATA OF TEST OF QUADRUPLE-EXPANSION PUMPING ENGINE, WILDWOOD STATION, PITTSBURG, PA., MARCH 24 TO 26, 1899.

DIMENSIONS.

	I	III	II	IV
Number of steam cylinder				
Length of stroke.....inches	42	42	42	42
Diameter of steam cylinder..... "	19.5	49.5	29.0	57.5
Diameter of piston rod, top..... "	3.625	.....	3.625	.....
Diameter of piston rod, bottom ..... "	4.5	3.625	4.5	3.625
Net area pistons, top side ..... sq. in.	288.327	1,924.43	650.2	2,596.73
Net area pistons, bottom side..... "	282.744	1,914.11	644.6	2,586.40
H.P. per 1 lb. M.E.P., 36.5 revs., top, H.P.	1.1162	7.499	2.517	10.052
" " " " bottom "	1.095	7.410	2.496	10.013
Clearance on steam cylinders. ...per cent.	1.25	0.55	1.30	0.36

	A	B
Pump cylinders		
Length of stroke .....inches	42	42
Diameter of plunger ..... "	14.75	14.75
Diameter of rod..... "	4.50	4.50

Cylinder displacement per revolution, cubic feet	15.8396
" " " " gallons	118.388
Weight of water pumped per revolution, pounds	988.65
Elevation, top of tunnel above sea level, feet	704
" bottom " " "	698
" bedplate of engine, bottom level, feet	708.21
" centre of gauge on force main, "	717.3
" bedplate of engine, top "	710.63
" centre of gauge on suction main, "	717.98
" weir notch, by specifications, "	1,310.00
" " per James Harlow, "	1,308.92
" " by breadth	3.14

PRESSURES.

Steam Pressures.

Boiler pressure, gauge, pounds per square inch	199.87
Barometric pressure, inches	28.90
" " pounds	14.19
Absolute pressure in boiler, pounds	214.00
Vacuum gauge, inches	26.60
Jacket No. 1, gauge, pounds	199.81
Receiver No. 1, gauge, pounds	85.47
Jacket No. 2, "	116.05
Receiver No. 2, "	24.77
Jacket No. 3, "	39.78
Receiver No. 3, inches of mercury	—1.59
Jacket No. 4, pounds	38.74
Reheater No. 1, pounds	102.08
" No. 2, "	103.69
" No. 3, "	105.36

Water Pressure.

Force main, pounds per square inch	258.12
Vacuum gauge, inches	6.80

GENERAL DATA.

Duration of trial, hours	36
Work per revolution	595,849.49
Total number of revolutions	78,876
Revolutions per hour	2,191
Revolutions per minute	36.52
Pressure on gauge on force main, pounds	258.12
Head in feet on force main, feet	595.57
Vacuum gauge on suction main	6.80
Suction in feet below pressure gauge	6.92
Total head from gauge, corrected, feet	602.69
" by survey, feet	598.625
" by specification, feet	599.70
Total feed-water, pounds	318,614.4
Feed-water, pounds per hour	8,850.4

TEMPERATURE, DEGREES FAHR.

Outside air	34.9
Inside air	74.1
Water pumped	42.65
In outside upper tank	88.15
In pipe to exhaust heater	88.06
Between exhaust heater and heater I	104.9
Between heater I and heater II	136.5
In heater II	193.3
In heater III	260.43
In heater IV	311.0
Boiler feed	310.8
Receiver II to heater III	198.32

HEAT PER POUND STEAM.

Calorimeter in Main Steam Pipe.

Temperature in calorimeter, degrees Fahr	306.1
Back pressure, inches of mercury	9.0
" absolute, inches	37.90
" " pounds	18.65
Boiling temperature in calorimeter, degrees Fahr	224.3
Quality of steam to engine, per cent	98.74

Jacket Calorimeter.

Calorimeter temperature, degrees Fahr	298.1
Back pressure in calorimeter, inches of mercury	5.5
Absolute pressure in calorimeter, inches of mercury	33.95
" " " pounds	16.70

Boiling temperature on calorimeter, degrees Fahr.	218.7
Quality of steam to jackets, per cent	97.99
Heat per pound web steam to engine (from 32 degrees Fahr.)	1,189.52
" " " jacket " "	1,183.23
" " " mean " "	1,188.62
Temperature of feed-water	310.8
" " above 32 degrees	278.8
Heat absorbed per pound steam, B.T.U.	909.8

WORK OF STEAM CYLINDERS.

Number of steam cylinder	I	III	II	IV
M.E.P., top	69.35	12.85	35.16	8.85
M.E.P., bottom	70.68	14.02	33.98	9.33
I.H.P., top	77.56	96.58	88.64	89.14
I.H.P., bottom	77.55	104.09	84.99	93.63
I.H.P.	155.11	200.67	173.63	182.77

I.H.P., total	712.18
Feed-water per hour, total	8,850.4
Dry steam per hour, total	8,732.4
Dry steam per I.H.P. per hour	12.263
B.T.U. per I.H.P. per minute (above feed-water temperature)	185.96
" " " " hour	11,157.6

RESULTS OF PUMP TEST.

Capacity in 24 hours 86.52 revs. by plunger displacement, gallons	6,225,052
Work of lifting water, from pump diagrams, horse-power	662.67
Work consumed in overcoming friction, horse-power	49.51
Work consumed in overcoming friction, per cent	6.95
Friction head in pipe, difference between survey and gauge readings	2.5 ft. to 4.0 ft.
Friction head in pipe, difference between survey and gauge readings, per cent	0.41 to 0.61
Reduced friction of engine, per cent	6.12

DUTY OF PUMP.

Per one million B.T.U. $\frac{595{,}849.49 \times 2{,}191}{8{,}850.4 \times 909.8} = 162{,}948{,}824$ millions of foot-pounds.

Per one thousand pounds dry steam $\frac{595{,}849.49 \times 2{,}191}{8{,}732.4 \times 1{,}000} = 150{,}254{,}138$ millions of foot-pounds.

The Combined Indicator Diagrams of this engine, the one with and the other without heaters in use, are exhibited in Figs. 35 and 36. The difference is less than would perhaps have been anticipated; but it is nevertheless a very observable one. The series of saturation curves of the cylinders is discontinuous in the first and very nearly continuous in the second case; show-

ing the effect of the heaters in improving the action of the engine, by reducing the amount of steam taken into each cylinder for equal powers, and by increasing the completeness of re-evaporation during the progress of the stroke of the piston. It is also observable that the quantity of steam taken into each successive cylinder is less by the amount of steam taken out for use in the heaters. Without heaters, the saturation line runs smoothly from end to end of the combined diagram, illustrating, further, the admirable proportion of these elements, in series, which has been secured by the designer. The success met with in the endeavor to secure small clearances is well exhibited in these diagrams; as is also the depression of the back-pressure line, throughout the whole period of the return stroke. The loss of work between cylinders is an unusually small proportion of the total area of the diagram, and the waste by rounding off of corners is less than is common in this class of engine. In this, also, as in almost all other engines making a record for economy and high duty, the terminal pressure is brought down to a comparatively low figure, here about eight pounds per square inch, absolute, and rarely less than seven or higher than ten, with the now usual high boiler pressures, approximating 200 pounds.

In studying these diagrams, it will be remembered that the saturation curve is that with which the expansion line of the diagram would have coincided, had the expanding steam been retained in the dry and saturated state.

A criterion by which such an engine may perhaps be best judged and compared with other steam engines of varying conditions, especially steam pressure, is the magnitude of the value of the constant a in the expression for quantity of heat consumed, per horse-power per minute or per hour, already given,

$$H = \frac{a}{\log p_1}.*$$

The values of the constant, a, have been found to be, for the ideal case of Carnot, about 18,000 British thermal units per *hour*, and to range upward to 36,000 for the best classes of simple engines; while the best examples of triple- and quadruple-expansion machines give, respectively, about 27,000 and 26,000

* See "Manual Steam Engine," vol. i., chap. viii.

British thermal units. The accompanying diagram (Fig. 12), constructed from the data of the trial by Messrs. Prince and Case, shows how pressure affects this constant for the case in hand, and how its value is influenced by the varying conditions of its operation; the measure being here taken as British thermal units per indicated horse-power per minute and per hour. The record is held, in earlier work, at about $a = 460$.

As computed for this case,

	Per Min.	Per Hour.
For ideal (Rankine) case	364	21,840
For Nordberg Engine	433	25,980
Same without heaters	479	28,740

thus, allowing for differences of pressure, making this engine, thus gauged, about five per cent. better than the record, to date, with its heaters in action, as described, and as in the official and formal trial. Without its heaters in action, its coefficient is lower than the record by about the same percentage; showing the practical value of the transfer of heat from the working to the compression side of the diagram, in the manner indicated by Bourne and described by Cotterill, here to be 10 per cent., a decidedly appreciable and useful quantity.

On a similar basis, the values of a for the earlier "record-breaker" of Reynolds, at 120 pounds steam pressure, are 465 and 27,900; for the later engine of Snow, at 160 pounds, about 450 and 27,000, and for that of Leavitt, at 185 pounds pressure, 458 and 27,480.

The heat absorbed and carried over by each pound of steam is here found to be but 909 British thermal units—which is low in comparison with that usually observed, even with the best of engines. The Carnot cycle would, with the same range of pressure, demand 840 British thermal units, per pound of steam circulating in the unit of time, and the figure for many engines of good make and in good order is about 1,100; while a fair average may be taken at 1,000, the feed being assumed to be supplied at about 190 degrees Fahr. as it reaches the boiler. The more perfect the cycle, obviously, the smaller the magnitude of this quantity, and it thus becomes a measure of that perfection, although its decrease causes a rise in weight of steam per indicated horse-power per hour, all other things equal.

It is further to be noted that, while it is true that a fair average may be taken as 1,000 British thermal units per pound for

ordinary practice, and while 1,000,000 heat-units may be taken as the equivalent of 1,000 pounds of steam and of 100 pounds of fuel in estimating duties, it is also true that where such differ-

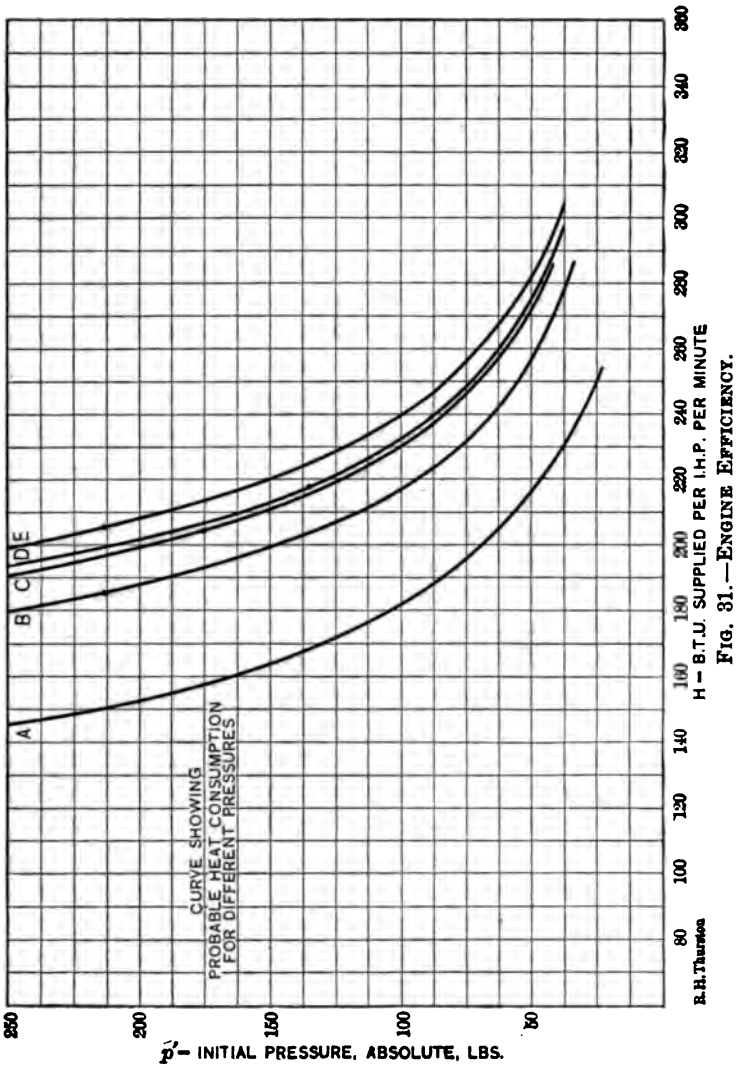
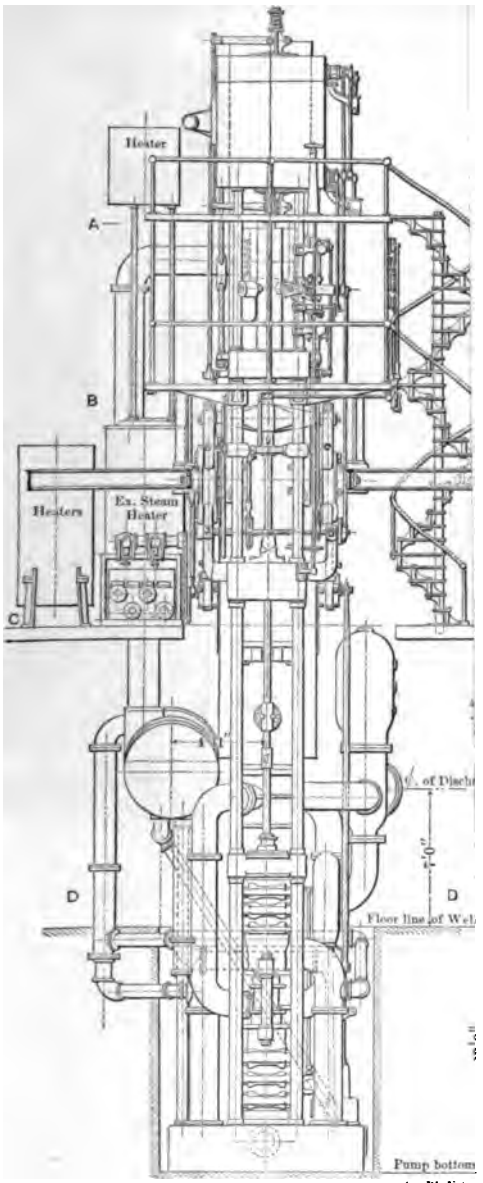


FIG. 31.—ENGINE EFFICIENCY.

ences occur among engines as those here referred to, important variations from accuracy may be found under such assumptions, and the thermal unit should always in these instances be taken as the basis of comparison. It is no longer the fact that 2.3 and 2.5 pounds of steam per indicated horse-power per hour,

FIG. 32.



ordinary practice, and while 1,000,000 heat-units may be taken as the equivalent of 1,000 pounds of steam and of 100 pounds of fuel in estimating duties, it is also true that where such differ-

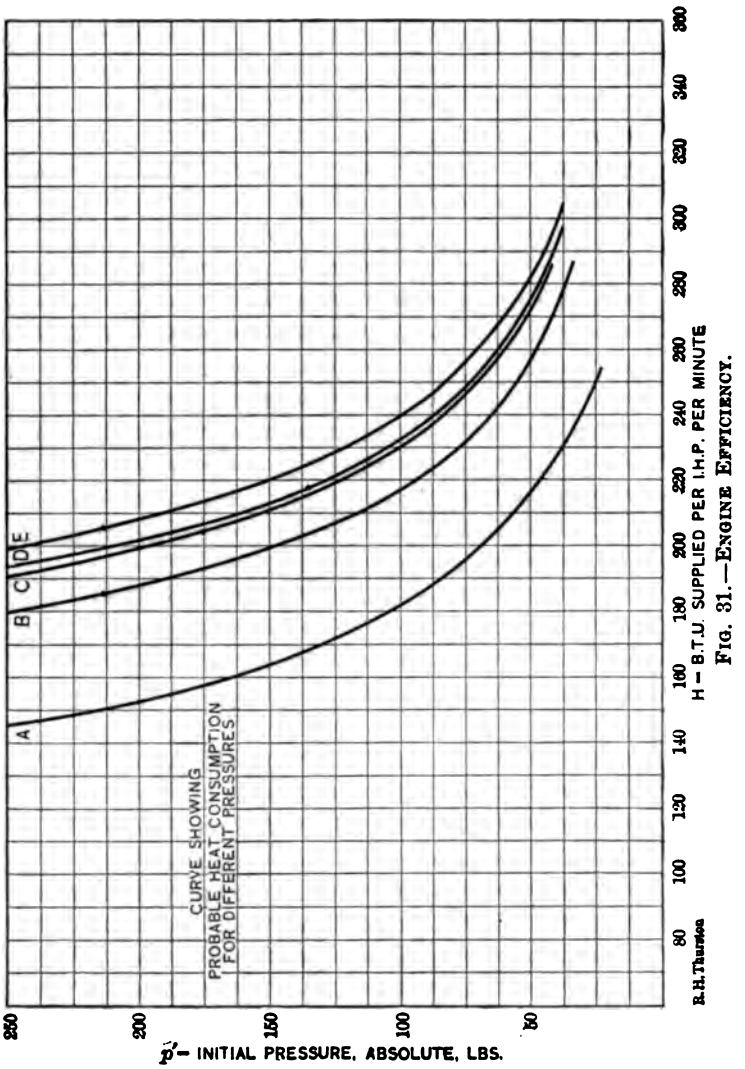
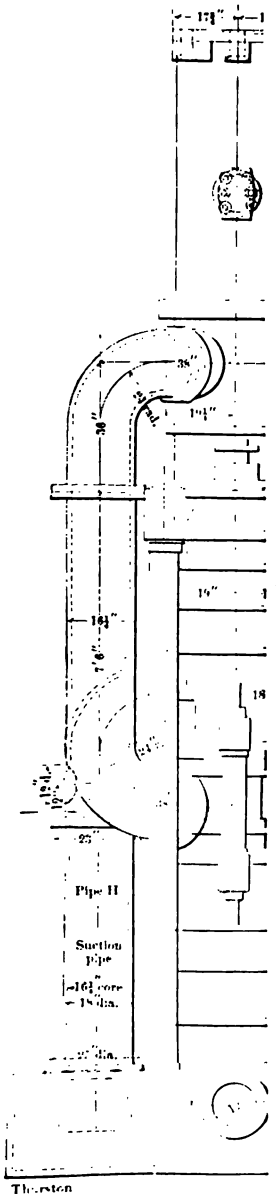


FIG. 31.—ENGINE EFFICIENCY.

ences occur among engines as those here referred to, important variations from accuracy may be found under such assumptions, and the thermal unit should always in these instances be taken as the basis of comparison. It is no longer the fact that 2.3 and 2.5 pounds of steam per indicated horse-power per hour,


Pipe H
Suction pipe
Thurston

respectively, for the non-condensing and the condensing engine, may be assumed as the consumption corresponding to efficiency unity. This weight rises as the cycle is improved, and may become, as just seen, 2.8, 10, or even 20 per cent. higher. The better the cycle, for a given efficiency, the *larger* the weight of steam demanded per horse-power, comparatively, and the larger the figure for unity efficiency. It is also to be noted that, with the perfect engine cycle, the lower the steam pressure, the larger the "latent heat," the *smaller* the weight of steam demanded in transfer of a given quantity of heat between boiler and engine and the *smaller* the weight of steam, per horse-power per time unit, for unity efficiency. As the real engine cycle approximates the perfect engine cycle, these variations become observable.

In all these cases, the records have been made on a basis which, directly or indirectly, rates the machine by its physical efficiency; while the true basis must ultimately be recognized as being work performed per unit of cost, including operating expenses, interest on investment, and of maintenance and replacement accounts. The basis here accepted is a measure of the perfection of the design, construction, and operation; the commercial basis involves, with this, the success of the responsible financial officer in making investments in the steam plant add to the dividend-paying capacity of the establishment of which it forms a part. This latter ultimate and basic requirement compels the designer to conform his work to the demands of the finance of the case, and forces him to proportion his steam plant for a lower expansion ratio, a lesser duty, and considerably reduced costs of construction. Thus it may be found that, in a representative case, the reduction of the expansion ratio to about seven-tenths its figure for maximum duty, and the resultant reduction of that duty to about seven-eighths the maximum, may prove commercially and financially advantageous.*

Just how far the use of this system should be affected by costs of construction, and how far commercial efficiency would be affected by changes of proportion and design, remains to be determined.

In Fig. 31, *A* is the curve of variation of efficiency, or of "duty" with varying pressure, for the ideal case; *B* is that for the case of the engine here reported, with its system of heaters

* "Manual of the Steam Engine," fourth edition, chap. vii., 1898.

in operation; *C* is the curve for the Chestnut Hill engine; *D* that for the Milwaukee machine; and *E* is the curve for the engine reported, without its heaters. The working pressures of the several engines are indicated by the position of the points marked upon the curves of each. The effect of the adoption of this approximation to the Carnot or the Stirling idea, rough though it is, is here well shown as carrying the curve over to the left and well within the best of the preceding cases. The stakes are thus set well ahead of the record, and stand as a challenge to the ablest designers and constructors of the coming century. In this comparison, improvement is measured by the shifting of the curves toward the left.

Comparing the duty reported with the series represented by the duty-curve given as Fig. 23 in the introductory portion of this paper, it is interesting to note that the performance of this machine is just what had been thus, by our "scientific prophecy," indicated as to be anticipated for the record-breaker of its date. It would seem probable, however, that the curve must soon alter its line and possibly ere long assume a reversed curvature; since only increasing pressure can be relied upon, after a little, for further gain.

The deduction from the results of the trial here reported upon would seem to be that the use of auxiliary heaters, heating the feed-water by transfer of heat from the expansion side of the engine to the side of heat supply, is correct practice; being justified by experience as well as by the theory advanced by Cotterill. The extensive use of heaters, employing steam direct from the receivers of the older types of multiple-cylinder engines, has been for some years practised also in Europe, and these "prime-steam heaters," as they have sometimes been called, have usually been found to justify their introduction.

The End of the Nineteenth Century is that of one which will always remain preëminent in history as the age in which the steam engine took shape in the hands of Watt and Sickles, and Corliss and Greene, of Porter and their successors, and thus brought in the factory system and all our modern methods of production, with their resultant effects in the reduction of costs of production, in the improvement of the condition of the people and in all the material advancement in the industrial arts which has made the century distinctively one of supremacy of the mechanic arts. The close of the century finds the steam engine, though

threatened with displacement by other motors, in the view of many writers, nevertheless the great motor of the age. Substantially all of the power employed by the civilized world is supplied by this great invention—congeries of inventions rather—the product of a series of improvements, of an evolution, effected during the hundred years or more just past. The limit to be possibly attained in its development and perfection will always remain a subject of intense interest to the profession and to the world.

Summarizing, we may state that the limit of progress attained to date is variously measured by these figures:

APPROXIMATE DATA IN BEST PRACTICE.

Duty on basis of 1,000,000 B. T. U., foot-pounds	163,000,000
Economy measured in B. T. U., per hour, per H. P.	11,160
Economy measured in B. T. U., per H. P., per minute	186
Economy, lbs. steam at 1,000 B. T. U., per lb., per hour, per H. P.	11.16
Economy in best fuel, 15,000 B. T. U., per lb.; boiler at 80 per cent. efficiency, lbs. per hour, per H. P.	1
Economy measured by a in $H=a/\log p_1$	433
Efficiency measured against perfect engine of Carnot, per cent.	84

Reviewing the history of the growth of this form of steam engine, it will be seen that its progress has illustrated that of the machine in all its forms, and that the steam pumping engine gives the engineer a record of greater extent and of more representative character, as exemplifying the evolution of the machine, than does any other type.

The curves of progress which the writer has presented here and elsewhere,* are seen to cover the whole period, and, even though constructed some years before the end of the century, to represent with practical accuracy the path of improvement to its close. The twentieth century will very probably see a change in the curve of our lines, if not, in some respects, a decided halt or a reversed curvature, and it is perhaps even more probable that the field of the steam engine will become greatly restricted by the introduction of other heat motors, as well as by the general employment of electricity as a medium of extensive power distribution from hydraulic and pneumatic prime

* "The Trend of National Progress," *North American Review*, September, 1895. "History of the Growth of the Steam Engine," fourth edition. New York, D. Appleton & Co., 1898.

movers. The steam engine has now been so far perfected, and the practical limits of pressure are coming to be so nearly approached by steam-boiler constructers and users, that but little more can be expected of the designer; and, even with the costlier types of engine, practically justifiable with exceptionally high costs of fuel, uninterrupted working and low values of money, as in some instances with the steam pumping engine, commercially practicable progress seems likely to prove very slow henceforth. These costly types of engine must necessarily have a comparatively narrow field. With the common case of moderate cost of fuel, intermittent duty, comparatively high value of money in the business, or absolute scarcity with the buyer, gains seem likely hereafter to be rather in the direction of cheapened methods of construction and simplification of design.

APPENDIX.

Appended is a collection of selected data, Table VII., supplied by Mr. Bryan Donkin to *The Engineer* (London) of October 13, 1899, exhibiting the best performance of the best engines, so far as reported to date, and as corrected by him for the writer. They include all steam-pumping engines which have been noted by the collator, a collection of Sulzer engines in a second group, and all other mill engines in the third group.

In studying these figures and making deductions therefrom, the following points must be carefully borne in mind: the "order of merit," where engines differ, as do these, in steam pressure, and especially in temperature of feed-water, is not, as assumed by its author, weight of steam consumed per unit of power developed, net, but *quantity of heat supplied;* the columns at the right, giving British thermal units per indicated horse-power per minute and duty in foot-pounds per million British thermal units, and that giving the value of A/B, establish the order of merit as thermodynamic machines, and correctly measure their efficiency. It is further to be observed that the unit of weight of fuel taken in duty computations in the United States is not the "hundredweight" (cwt. = 112 pounds), but 100 pounds, differing 12 per cent. from the British standard, and correspondingly altering the apparent relative standing of engines on the opposite sides of the Atlantic. All figures should be carefully checked; those for the Milwaukee in column 11

are transposed, and the official figure is slightly in error; it is actually 11.7 pounds dry steam. The list does not include the Snow engine at Indianapolis or Leavitt's Chestnut Hill engine, which are among the most remarkable of American engines.

The figures for the mill engines of Sulzer are incomplete and extraordinarily low for the class of engine; but the trials are not authoritative, cases 2 and 3 perhaps excepted. Comparison of set No. 2 with set No. 3 indicates the advisability of caution in the adoption of such figures as are tabulated in the former set. *A priori*, one would expect practically lower efficiencies from the mill engine than from the pumping engine; its disadvantage being its less constant and less long-continued operation.

DISCUSSION.

Mr. J. B. Stanwood.—In reading Professor Thurston's paper my interest was awakened to compare the gain of the theoretically perfect Nordberg cycle (expansion being in four stages) over a perfect Rankine cycle, operating under same range of temperature, with the gain obtained actually in practice as reported.

By means of the temperature-entropy diagram (Fig. 37), which shows graphically the transfer of heat to and from 1 pound of H_2O as it makes one complete cycle, I have obtained the following results: Assuming the highest temperature of H_2O, corresponding to the boiler pressure of 214 pounds absolute, to be 387 degrees Fahr., equal to 848 degrees absolute, and lowest temperature to be 104 degrees Fahr., equal to 565 degrees absolute, corresponding to pressure in condenser of 26.6 inches below a barometric pressure of 28.9 inches of mercury or $1\frac{1}{8}$ pounds absolute; it follows that the efficiency for the Rankine cycle is .3038; and for the Nordberg cycle is .3284, where the receiver temperatures absolute are 788 degrees, 726 degrees, and 668 degrees, corresponding respectively to receiver pressures (as given) of 99.6 pounds, 38.9 pounds, and 13.4 pounds absolute.

The Carnot efficiency for same range of temperature is .3337.

(I submit a temperature-entropy diagram and calculations by which these results are obtained.)

The theoretical gain for the Nordberg over the Rankine cycle in this case is $\frac{.3284 - .3038}{.3038}$ per cent. equals $8\frac{1}{10}$ per cent. nearly.

In the test made, as reported, the actual gain was about 10

per cent., or nearly 25 per cent. more than the above would warrant.

If this is true, to what is due this excess gain?

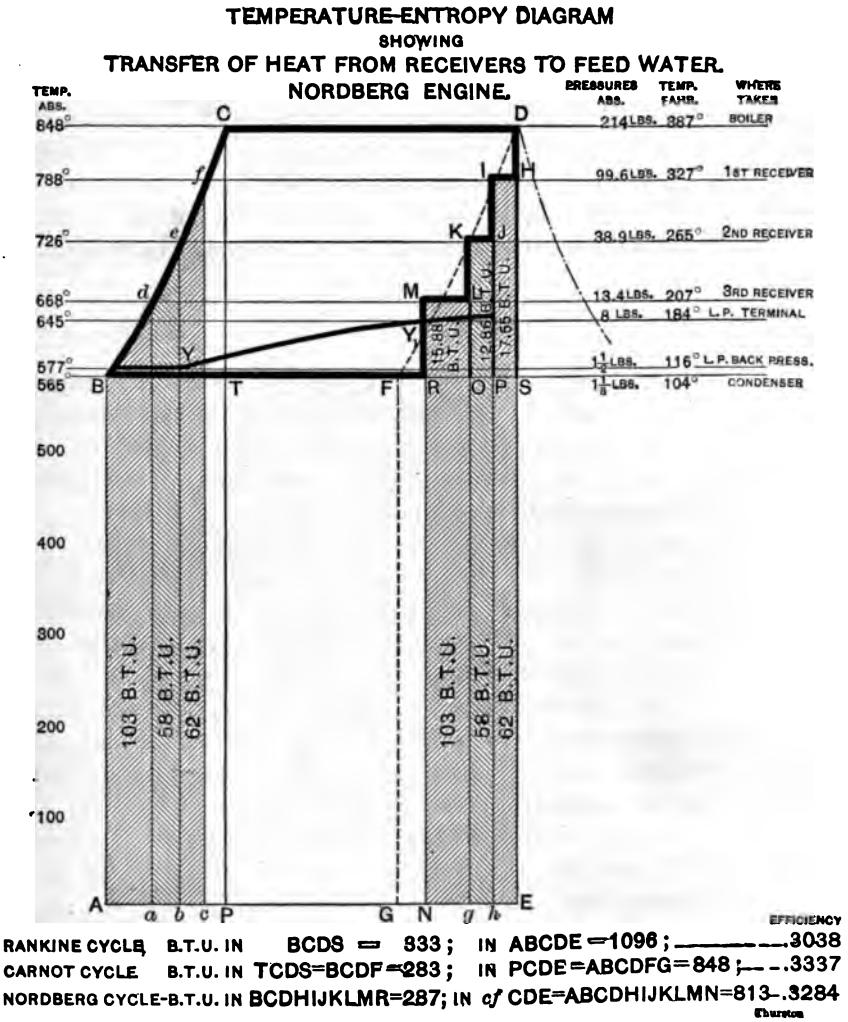


FIG. 37.

In considering the matter, especially in the light of the temperature-entropy diagram, it seems to me that it can be shown that, by means of progressive feed-water heaters receiving heat from the receiver of a multi-cylinder expansion engine, a reduc-

tion of the free expansion loss at the end of expansion in the low-pressure cylinder can be effected, because the terminal pressure is lowered thereby; securing a gain which can be added to that obtained by the employment of the better cycle.

The terminal pressure measured on combined diagram as published, without heaters, is nearly 10 pounds absolute. The same measured with heaters is nearly 8 pounds absolute.

The free expansion loss, in the first case, to a condenser pressure of $1\frac{1}{8}$ pounds absolute is 56 British thermal units. In the second case, the loss is 45 British thermal units per pound of H_2O, or a difference of 11 British thermal units. When heaters are employed, these heat units, on account of the usual incomplete expansion, are not drawn from effective work, but from heat otherwise rejected, and are utilized in raising the temperature of the feed-water. In this instance the heat units withdrawn from work in low pressure, second and first intermediate cylinders are respectively 15.9, 12.8, and 17.6 British thermal units, or a total of 46.3 British thermal units. But on account of incomplete expansion, 11 British thermal units of this can be secured from otherwise rejected steam, and the deduction from effective work can be reduced $\frac{11}{46.3}$, or about 23 per cent., which is an amount sufficiently large to account for the difference to which allusion has already been made. The space on temperature-entropy diagram between the base line BS and the broken and curved line XYY, shows the loss of heat (roughly) thrown away by free expansion in low-pressure cylinder, and the diagram shows how part of the heat for feed can be secured from heat rejected here, instead of from effective work.

Calculations from Temperature-Entropy Diagram.

The diagram is drawn to suit range of temperature as already explained. The full figure $ABCDE$ represents the total British thermal units delivered to 1 pound of H_2O in raising it from a feed-water temperature of 104 degrees Fahr., and converting it into steam at 210 pounds absolute pressure, or 1,096 British thermal units. Area $BCDS$ represents the greatest amount of work, in British thermal units, that can be obtained by a perfect Rankine cycle under these conditions, and is calculated by the formula:

$$W = (T - T_1)\left(1 + \frac{L}{T}\right) - T_1\left(\text{hyp}\cdot\log\frac{T}{T_1}\right),$$

where W is work expressed in British thermal units.

T = maximum absolute temperature of H_2O = 848 degrees.

T_1 = " " " " " = 565 "

L = latent heat of evaporation of H_2O at T = 839 British thermal units (Kent's tables).

The value of W in this case is 333 British thermal units.

The ratio of areas *BCDS* to *ABCDE* is the efficiency of the cycle = .3038.

In the Nordberg cycle, an amount of heat must be drawn from the receivers to heat the feed-water to the respective receiver temperatures. To raise the feed from 104 degrees Fahr. to 207 degrees takes 103 British thermal units; from 207 degrees to 265 degrees takes 58 British thermal units; from 265 degrees to 327 degrees takes 62 British thermal units.

These amounts to heat feed-water, as supplied in a Rankine cycle (by the boiler), are shown to left of diagram by areas *ABda*, *adeb*, and *befc*.

If the heat for this purpose is transferred, as in the Nordberg cycle, from expanding steam, equivalent amounts must be taken from the receivers III., II., and I., respectively, and are shown by rectangles on the right of the diagram. The work which is sacrificed by this transfer is shown for the low pressure, second, and first intermediate cylinders by the amounts 15.9, 12.8, and 17.6 British thermal units respectively, as shown by rectangles *RMLO.*, *OKJP*, and *PIHS*.

The values obtained for these areas are as follows:

Work lost in low-pressure cylinder $= \frac{103}{668} \times 103$ British thermal units = 15.9 British thermal units.

Work lost in second intermediate cylinder $= \frac{161}{726} \times 58$ British thermal units = 12.8 British thermal units.

Work lost in first intermediate cylinder $= \frac{223}{788} \times 62$ British thermal units = 17.6 British thermal units.

The maximum work of the Nordberg cycle then equals the Rankine cycle less the sum of the above; or is 333 − (15.9 + 12.8 + 17.6) = 286.7 British thermal units, represented by area

BCDHIJKLMR. The heat applied will equal that applied in the Rankine cycle, less the amount necessary to raise feed-water to temperature of first receiver, or 1,096 – 223 British thermal units = 837 British thermal units, and is represented by the area $cfCDE$ = area *ABCDHIJKLMN.*

The Nordberg efficiency will be $\frac{286.7}{873} = .3284$, which is greater than the Rankine efficiency.

The Carnot efficiency is the ratio between rectangles *TCDS*, or the equivalent area *BCDF*, and the rectangle *PCDE*, which is the same as the well-known relation $\frac{T - T_1}{T}$, or, in this case, $\frac{848 - 565}{848} = .3337$.

Mr. Charles T. Porter.—Mr. President, in reading Professor Thurston's paper, the question occurred to me: Is not the presentation of it at this time somewhat premature? Might it not have been better to have postponed its preparation until after the close of the century? The title of the paper is "The Steam Engine at the Close of the Nineteenth Century." But, Mr. President, we have not reached that point yet. It is more than a year before us. Judging from the past, it is obvious that many things will transpire in the year that is to come, some of which should find a place in this record. I intend myself, Mr. President, before the century has expired, to give the professor something more to write about.

Starting from the steam engine, a description of which I had the honor to present to the Society at its New York meeting in 1894, five years ago, and from the boiler invented by Mr. John F. Allen, and which was exhibited by me at the fair of the American Institute in this city in 1870, twenty-nine years ago, a boiler which Professor Thurston will remember very well; from these two starting points, Mr. President, I have, during the last five years, devoted myself largely to the maturing of a comprehensive system, to which I have ventured to give the name of "The New Engineering," the primary object of which, I may say—among other objects—is to obtain a horse-power from the evaporation of 9 pounds of water per hour. It has been a big job, Mr. President. It has taken a good while. Many

questions have had to be determined, and problems to be solved—constructive problems and others—most of which have had to lie for a long time, waiting for their proper solution to appear; and it is only quite recently that I have felt satisfied that the system as a whole had reached its maturity, and that I should be able—as I now distinctly see myself able—to obtain a horse-power from this evaporation of 9 pounds of water per hour. I fully intend, if possible, to have this system in operation before the close of the century, and I would therefore beg Professor Thurston not to seal up the record to-day, but to leave it open, if he will kindly do so, and give me a place on the last page. (Applause.)

The President.—Mr. Porter, if you please; you stated you believed that you could obtain a horse-power from 9 pounds of water. Would it be proper that you might explain to the Society, which, no doubt, would be of great interest to them, the manner in which you expect to obtain that economy?

Mr. Porter.—That is a very natural question, Mr. President, and it will give me pleasure to answer it. I rely primarily upon 300 pounds' boiler pressure, with 30 expansions.

My boiler will carry this pressure with a factor of safety nowhere less than 10 and ranging from that to 20. Its members are all free at one end, or at both ends, and so are not subject to strains from expansion, and, as it will contain no scale or sediment, it cannot be injured by overheating. The boiler is, therefore, under this pressure preëminently safe and durable.

I obtain the expansions by cutting off at .4 of the stroke in each cylinder of a quadruple series, as a fixed point of cut-off. In each cylinder the expansion is carried practically to the end of the stroke. The cylinders are so proportioned, that the steam is transferred from one to another without change of volume—no drop—and the communications are such, that a scarcely sensible fall of pressure is occasioned between the cylinders, or between the last cylinder and the condenser. The cut-off would give 39 expansions, were it not for the waste room. This reduces the number to about 30, raising the terminal pressure from 8 pounds to 10.5 pounds. It occasions no loss, as in all the cylinders except the last, compression commencing at the terminal pressure rises to the initial.

This combination gives a great number of expansions, with a high mean pressure; the back pressure bears a small ratio—

from one-half to one-quarter of the usual ratio—to the mean effective pressure; the vacuum will be better, from the absence of water to be reëvaporated on the exhaust; and on account of improved construction it will be more nearly realized in the cylinder. From these features I anticipate an economy *over the best hitherto obtained* of from 10 to 15 per cent.

This combination will also give from twice to three times as much power from the same cylinders, with the same piston speed, as is ordinarily obtained, and the jackets will be supplied with steam of higher temperature.

I rely, secondly, on my system of superheating and reheating. This is of great consequence, partly because without it the economy already described would not be realized.

I do not employ reheaters. The reheater has no effect on the steam in the first cylinder. But it is in this cylinder that most of the loss is suffered. This is from two causes: *First.* The work done in this cylinder is that of the total mean pressure, and in my engine is more than 40 per cent. of the whole. Of this work, considerably less than one-half is effective on the first piston, the rest being transmitted to the succeeding cylinders; but the reaction is all against the first piston, and so in this cylinder all this work is done, and the corresponding condensation takes place.

Second. All the initial condensation, which is much more than that caused by the conversion of heat into work, takes place in the first cylinder. The same action in the succeeding cylinders —condensing and reëvaporating the same steam over again—only passes on to the condenser the heat which was lost in the first cylinder. Both these losses can be prevented only by using superheated steam. But superheated steam cannot be used in the jackets; it would ruin their action. This is because at 300 pounds pressure steam contains only about one-thirtieth the quantity of heat that is contained in the same volume of water, and if the steam is superheated the proportion is still less. When saturated steam in the jacket imparts heat to its cast-iron envelope, it is condensed and covers the surface with a film of water. This water, receiving continual accessions of heat from the condensing steam, imparts heat to the cylinder thirty times more rapidly than dry steam could do.

I *must* have superheated steam in the first cylinder, and I *cannot* use superheated steam in the jackets. My boiler gets me

out of this dilemma. It will supply saturated steam to the jackets, and to the first cylinder steam superheated to the degree required to supply the heat here to be converted into work. Superheated steam also prevents initial condensation entirely, while very little of its temperature is lost by it on entering the cylinder, on account of the quality that makes it useless in the jacket.

Again, respecting reheaters, it is to be noted that the condensing and reëvaporating action of the surfaces of the heads and pistons in the succeeding cylinders operates to neutralize the gain derived from them. My steam jackets on all the cylinders embrace the ports and the internal steam pipes, which are quite distinct from the cylinder, and embrace also the heads and the pistons, so that there is no surface whatever to exert a contrary influence. I do not attach so much consequence to the jacketing of the cylinder wall itself, as I do to the jacketing of those parts, the surfaces of which, exposed to the steam, are in the state in which they come from the foundry; because when water appears in a cylinder as the product of the conversion of heat into work, it appears in a fine mist distributed through the steam, and must be reëvaporated chiefly by radiation; and we know that the radiating power of polished iron is not more than 20 per cent. of that of rough iron, so that my principal reliance is upon the surfaces which remain as they come from the foundry. I have incidentally an advantage in this respect. My divided ports present quite an extended surface relatively to their area, and, in addition to that, the internal steam pipes leading to the ports present considerable internal surface. I find the aggregate of the internal surfaces presented by these steam pipes and the ports to be 60 per cent. greater than the aggregate surfaces of the two heads and the two sides of the piston, in each cylinder. That is a material addition to those important surfaces. Now we know very well the wonderful efficiency of these surfaces for harm. Before the compound engine was introduced, we know the great losses that were occasioned by their action, and all sort of schemes were suggested to prevent that action. I propose to make these surfaces as effective for saving heat as they have been for wasting it. For this purpose I introduce steam at the boiler pressure into the jackets and heads and pistons. The vertical engine, among its other advantages, affords admirable facilities for drainage, which only require to

be utilized by proper construction. I have drained my heads, jackets, and pistons very well and they automatically free themselves also from air, which, if it accumulates in the jacket pretty much, ruins its action—if it accumulates sufficiently. Now this temperature in the jackets, heads, and pistons being about 430 degrees, these surfaces are quite sufficient not only to prevent initial condensation and reëvaporate the water that is formed from work done, in the second, third, and fourth cylinders, but also to superheat the steam in them, so as first to raise the expansion curve to the theoretical, which it would fall below quite a little on account of the cooling of the steam, and far more than that, to superheat the steam in these cylinders, especially in the last, to a degree that I do not know where the limit is, but it would be pretty high, if you choose to use it. The question is, How far would it be advantageous to carry this superheating? and that seems to be the only question. I have made provision for determining that question experimentally in this way: The jackets of the low-pressure cylinders will carry the full pressure safely, if I wish to have it there, and provision is made for reducing that pressure as much as may be found desirable. I expect that the pressure in the jackets of these last cylinders may be reduced to 50 pounds. The large saving from this system of superheating and reheating is obvious.

The third ground of my confidence is the use of a fixed point of cut-off and throttling regulation, in place of the variable cut-off. I have one uniform expansion. Whether the engine is doing its full work, all that it is capable of doing, or to whatever extent the load upon it may be diminished, it is immaterial; the expansion is always the same, about thirty-fold.

Then the variable cut-off gives a varying volume of chamber up to the point of cut-off, to receive the constant volume of steam that is being exhausted from the preceding cylinder. With a varying load, that variation is very great, forming chambers far too large, or far too small. I have a constant volume of area to receive the constant volume of steam.

But, above all, the variable cut-off maintains the extreme heat interval, between the temperature of the admission and the temperature of the exhaust, however early the steam may be cut off, and every engineer knows that this heat interval is the thing to be got rid of, as far as possible; that this is the greatest cause of loss of heat in the steam engine. In place of

this, I employ throttling. First, throttling superheats the steam. For every degree by which the temperature of one pound of steam is lowered by throttling, we have liberated one-third of a unit of heat; that one-third of a unit of heat will superheat a pound of steam two-thirds of a degree, the specific heat of steam being .48; so that throttling is a means of additionally superheating the steam before it enters the engine at all. Then the more the steam is throttled, the shorter the heat interval becomes, and there we have an important source of gain.

The superheating by means of the jacket becomes also more and more efficient, as the pressure in the cylinder becomes lower and lower; less work being done, there is less wet steam to be dried and superheated. That is my third ground of confidence.

The fourth ground of my confidence—I will have to lug it in, I think, but I do not want to omit it—is the high piston speed which I employ. Now I do not think that, under the conditions existing in my engine, high piston speed will reduce any further the weight of water evaporated per horse-power; but I do think that it is *necessary*, in order to render the economy here described practically available.

With slow piston speeds and long strokes, quadruple engines giving 30 expansions would be so large, so heavy, so expensive, and would occupy so much room, that they would not be used. But high speed combined with high pressure changes all this, as by magic.

I employ a piston speed of 1,250 feet per minute, with a stroke of 30 inches, giving 250 revolutions per minute in the largest engines; by which I mean engines of from 5,000 to 10,000 horse-powers. I do not intend this system for engines below 1,000 horse-powers.

Now, if we compare an engine having a piston speed of 1,250 feet per minute, with one running at one-half this speed, or 625 feet per minute, we see that we require only one-half the cylinder area to get the same power. But we have seen, also, that by doubling the steam pressure we, at the least, halve the cylinder area again. Now I combine these, and so require cylinders of only one-half the *diameter*, one-quarter the area, or even less. This, Mr. President, in quadruple engines, will be seen at once to be a most important reduction; for example, 50 inches diameter, in place of 100 inches diameter.

But I do not stop here in dividing by two. I employ also only one-half the stroke, and so I have cylinders of one-half the diameters and one-half the stroke, with a corresponding reduction in the dimensions of every part of the engine.

And then we find this combination of speed and stroke to present other important advantages, in whatever way we may look at it. For example, my engine is a three-crank engine, the cranks forming the usual angle of 120 degrees with each other. Now the shaft receives 25 rotative impulses per second, and, I may add, these impulses are, practically, exactly equal to each other, and they are applied at the end of cranks 15 inches long.

Now when we compare these with the impulses required to exert the same power from cylinders of four times the area, of double the stroke, and one-half the piston speed, we see that the latter will be each twice as strong, and applied at the ends of cranks twice as long, and at the rate of only 6¼ impulses per second. The great reduction in the size of the shaft required is readily computed. We discover, also, that we need little or no flywheel. Generally the momentum of the revolving parts—the cranks, armatures, pulleys, or gears—will incidentally be sufficient to maintain a closer approach to uniform rotation than any slowly revolving flywheel can give; and when we consider the enormous flywheels which are found to be required at present, we must rejoice that the steam engine is to be delivered from all such burdens. Then dynamos of only one-quarter the diameter are needed to give to the armatures the same circumferential velocity. Pulleys or gears are reduced in like manner, and often in mills the engine may be in the line of shafting, dispensing altogether with the means for getting up speed.

Then the friction on the shaft bearings is reduced by all the weight that is got rid of, and, the upward and downward impulses on the three cranks as a whole balancing each other, this friction becomes very small indeed. Then, also, this engine, free from fly-wheel momentum, can be stopped, by means provided for that purpose, in one-quarter of a second.

Then again, high speed is essential to smooth running. The crank passes its dead points under the stress of the full centrifugal force of the reciprocating parts of the engine, which increases as the square of the revolutions. At the speed employed by me, with proper weight in these parts, this stress is in excess of the initial force of the steam. An engine running

certainly is a more complete explanation of the operation of the machine and of its unique efficiency than the more general statements made in the paper.

Mr. Porter.—May I reply, Mr. President?

The President.—Yes, sir.

Mr. Porter.—I do not think, Mr. President, that I shall switch off on to the steam turbine, so long as the steam turbine consumes more than twice the quantity of steam that my system requires. (Laughter.)

Dr. Thurston.—I assumed that Mr. Porter was to bring the steam turbine down to something lower than he apparently considers possible.

Mr. A. M. Mattice.—I think it would add to the historical value of Professor Thurston's very interesting paper if he would supply the following data relative to the test of the Nordberg engine:

Weight of steam used in jackets and reheaters.

Weight of steam passing into cylinder, or the difference between the total steam and the preceding item.

Weight of steam accounted for by indicator cards at high-pressure cut-off.

Weight of steam not accounted for by indicator cards at high-pressure cut-off, expressed in per cent. of the steam passing into cylinders.

Per cent. cut-off in high-pressure cylinder.

Weight of coal used.

Duty in million foot pounds of useful work done per 100 pounds of coal.

Kind of coal.

Kind of boilers.

Kind of grates and stokers.

The five items last mentioned have nothing to do with the performance of the engine *per se*, but would be interesting for the purpose of comparing the performance of the whole plant with that of other installations.

Some of the items which I have asked for could be obtained approximately from the combined indicator cards given, but the errors caused by engraving and printing are often so great as to make any direct measurements unreliable.

*Prof. R. H. Thurston.**—The following statistics are supplied by Mr. Irving H. Reynolds:

* Author's closure, under the Rules.

Recent compound engines give the following results of trial: The Warren steam-mill engine (Reynolds), with steam at 140, produces the indicated horse-power on 12.45 pounds of steam per hour. The compound 30-million-gallon pumping engine at Louisville, Ky., by same designer, steam at 126, revolutions but 12½ a minute, gives a record of 12.71 pounds of steam per indicated horse-power per hour. Its piston speed is but 225 feet per minute. Its duty is 133,620,000, with a friction, due to low head—50 feet—of 14 per cent.

Of triple-expansion machines, those at St. Louis Water Works, described by Mr. Laird at the December meeting of the American Society of Mechanical Engineers, consume 11.6 pounds of steam per indicated horse-power per hour. The duty was about 160-, 000,000. The engines of the Cleveland, Ohio, Water Works have a duty of 161,993,814 foot-pounds per 1,000 pounds of dry steam, or 11.45 pounds per indicated horse-power per hour, with steam pressure 150. A very recent test of another such engine at the station of the Hackensack Water Company, New Milford, N. J., gives, as reported, 167,000,000 duty at 175 pounds pressure, on the more liberal basis, and 11 pounds of steam per indicated horse-power per hour. The 30-million engine of the Boston Water Works, of the same make, is reported by the superintendent of the station as giving a duty of from 152 to 157 millions per 100 pounds of fuel, a steam pressure being carried of 185 pounds.

The deduction follows, from these last examples, that it is practicable to secure an economy of 11 pounds of steam per indicated horse-power per hour, with less than 200 pounds pressure and without superheating or other exceptional expedients being resorted to. Taking this as a basis, we find that, the feed-water in this case being at a temperature of 150 degrees Fahr., the duty at 11 pounds consumption would be, with 1,100 British thermal units per pound, about 163 millions per million British thermal units; but without knowledge of the heat carried from boiler to engine by each pound of steam in the actual case, it is impossible to make accurate comparison, and where such differences exist in feed-water temperatures no conjecture is likely to prove correct.

certainly is a more complete explanation of the operation of the machine and of its unique efficiency than the more general statements made in the paper.

Mr. Porter.—May I reply, Mr. President?

The President.—Yes, sir.

Mr. Porter.—I do not think, Mr. President, that I shall switch off on to the steam turbine, so long as the steam turbine consumes more than twice the quantity of steam that my system requires. (Laughter.)

Dr. Thurston.—I assumed that Mr. Porter was to bring the steam turbine down to something lower than he apparently considers possible.

Mr. A. M. Mattice.—I think it would add to the historical value of Professor Thurston's very interesting paper if he would supply the following data relative to the test of the Nordberg engine:

Weight of steam used in jackets and reheaters.

Weight of steam passing into cylinder, or the difference between the total steam and the preceding item.

Weight of steam accounted for by indicator cards at high-pressure cut-off.

Weight of steam not accounted for by indicator cards at high-pressure cut-off, expressed in per cent. of the steam passing into cylinders.

Per cent. cut-off in high-pressure cylinder.

Weight of coal used.

Duty in million foot pounds of useful work done per 100 pounds of coal.

Kind of coal.

Kind of boilers.

Kind of grates and stokers.

The five items last mentioned have nothing to do with the performance of the engine *per se*, but would be interesting for the purpose of comparing the performance of the whole plant with that of other installations.

Some of the items which I have asked for could be obtained approximately from the combined indicator cards given, but the errors caused by engraving and printing are often so great as to make any direct measurements unreliable.

*Prof. R. H. Thurston.**—The following statistics are supplied by Mr. Irving H. Reynolds:

* Author's closure, under the Rules.

Recent compound engines give the following results of trial: The Warren steam-mill engine (Reynolds), with steam at 140, produces the indicated horse-power on 12.45 pounds of steam per hour. The compound 30-million-gallon pumping engine at Louisville, Ky., by same designer, steam at 126, revolutions but 12½ a minute, gives a record of 12.71 pounds of steam per indicated horse-power per hour. Its piston speed is but 225 feet per minute. Its duty is 133,620,000, with a friction, due to low head—50 feet—of 14 per cent.

Of triple-expansion machines, those at St. Louis Water Works, described by Mr. Laird at the December meeting of the American Society of Mechanical Engineers, consume 11.6 pounds of steam per indicated horse-power per hour. The duty was about 160-, 000,000. The engines of the Cleveland, Ohio, Water Works have a duty of 161,993,814 foot-pounds per 1,000 pounds of dry steam, or 11.45 pounds per indicated horse-power per hour, with steam pressure 150. A very recent test of another such engine at the station of the Hackensack Water Company, New Milford, N. J., gives, as reported, 167,000,000 duty at 175 pounds pressure, on the more liberal basis, and 11 pounds of steam per indicated horse-power per hour. The 30-million engine of the Boston Water Works, of the same make, is reported by the superintendent of the station as giving a duty of from 152 to 157 millions per 100 pounds of fuel, a steam pressure being carried of 185 pounds.

The deduction follows, from these last examples, that it is practicable to secure an economy of 11 pounds of steam per indicated horse-power per hour, with less than 200 pounds pressure and without superheating or other exceptional expedients being resorted to. Taking this as a basis, we find that, the feed-water in this case being at a temperature of 150 degrees Fahr., the duty at 11 pounds consumption would be, with 1,100 British thermal units per pound, about 163 millions per million British thermal units; but without knowledge of the heat carried from boiler to engine by each pound of steam in the actual case, it is impossible to make accurate comparison, and where such differences exist in feed-water temperatures no conjecture is likely to prove correct.

No. 833.*

FRICTION TESTS OF A LOCOMOTIVE SLIDE VALVE.

BY FRANK C. WAGNER, TERRE HAUTE, IND.
(Member of the Society.)

DURING some recent locomotive tests made at the Rose Polytechnic Institute, as a feature of thesis work by Messrs. Butler and Crebs, it was found desirable to operate one of the valves by means of an electric motor. It occurred to the writer that, by making a few additional observations, some useful data upon the friction of a locomotive slide valve might be obtained. The tests were made accordingly, and it is hoped that the results obtained may be found both interesting and useful.

The changes made upon the locomotive to adapt it to the tests were as follows:

The steam valve on one side was disconnected and blocked in middle position, so that no steam could enter the cylinder on that side. The locomotive was moved on the track until the piston on the other side was approximately in the middle of its stroke, and then the main drivers were securely blocked. At the same time the cross-head was also blocked. The back-up eccentric rod was then disconnected, and an extension piece was bolted to the link for the purpose of connecting with an external source of power for driving the link motion and through it the valve. The power in this case was furnished by an electric railway motor of 15 horse-power. On the end of the electric motor shaft was keyed a forged crank, with a one-inch steel crank-pin. The pin worked in a link block, which, in turn, slipped in a suitable slot cut in the extension piece to the main link.

By this arrangement the forward eccentric-rod pin served as a fulcrum for the link, and a reciprocating motion was imparted to the link by the electric motor through the medium of the crank and slot. The link block of the locomotive mechanism was left in place, and imparted motion to the valve in the usual way.

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

The movement of the valve could be regulated slightly by raising or lowering the link. Additional regulation of the amount of steam admitted to the cylinder was obtained by opening and closing the throttle.

Indicators were connected both to the cylinder and to the steam chest. The motion of the indicator drums was obtained directly from the valve stem, so that the length of the indicator card represents exactly the travel of the valve. The number of strokes of the valve was registered by a counter.

The power used to drive the valve was obtained by measuring the electrical power delivered to the electric motor, and making suitable allowances for the efficiency of the motor and the friction of the transmitting mechanism. This was done as follows: After the tests were completed, the valve stem was disconnected, and the electrical power required to drive the electric motor and transmitting mechanism was determined for various speeds. The efficiency of the electric motor under various loads had previously been determined in the laboratory. By comparing the efficiencies at the two loads, the increased loss of power in the electric motor when driving the valve, over and above the lost power when the valve was disconnected, was determined and allowed for.

No allowance was made for increased friction of the link-work. The crank pin and sliding block used to transmit the power from the motor shaft to the link were flooded with oil by dipping into a bath of oil and water with every revolution of the motor. The friction of other portions of the link-work and of the rocker arm was relatively small, and no great error can be introduced by considering it to be the same for the different loads at the same speed.

The dimensions of the valve experimented upon, and the results obtained, are given in Tables I. and II.

TABLE I.

DIMENSIONS OF VALVE.

Type of valve	D slide
Width of valve, inches	9.25
Length of valve, inches	17.00
Width of port opening, inches	1.25
Length of port opening, inches	15.00
Width of exhaust port, inches	2.50

Width of bridge, inches	1.25
Steam lap, inches	0.875
Exhaust lap, inches	0.125
Gross area of valve, square inches	157.25
Balanced area of valve, square inches	54.50
Unbalanced area of valve, square inches	102.75
Total bearing area of packing strips, square inches	22.20
Gross rubbing surface, bottom of valve, square inches	86.00
Average net rubbing surface, bottom of valve, for 8-inch stroke, square inches	58.20
Rubbing surface, top of valve, square inches	22.20

TABLE II.

FRICTION OF VALVE.

Number of test	1.	2.
Duration of test, hours	2.25	0.62
Number of observations	10.	3.
Double strokes of valve per minute	421.	410.
Speed of valve, feet per minute	210.5	205.
Average steam pressure in boiler, pounds per square inch	144.9	154.
Average steam pressure in steam chest, pounds per square inch	42.18	122.0
Downward force on valve due to pressure in steam chest, pounds	4,334.	12,534.
Average upward force on valve due to pressure in steam cylinder, pounds	373.	596.
Net force pressing valve upon its seat, pounds	3,961.	11,938.
Intensity of pressure between rubbing surfaces, face of valve, pounds per square inch	68.	205.1
Intensity of pressure between rubbing surfaces, packing strips, pounds per square inch	42.18	122.0
Average power delivered to electric motor during test, horse-powers	4.85	7.45
Power consumed in driving motor and link-work, horse-powers	3.30	4.14
Net power consumed in driving valve, horse-powers	1.55	3.31
Average force required to move valve, pounds	243.	533.
Drops of oil fed to valve per minute	20.	15.
Coefficient of friction	.050	.036

The average net rubbing surface on the bottom of the valve was found by subtracting from the total rubbing surface, on the face of the valve, the average amount of such surface which was over the ports during one stroke of the valve.

In calculating the force with which the valve is pressed upon its seat, allowance has been made for the upward pressure on the portions of the valve which extend over the steam ports. Both

the area thus acted upon and the pressure vary during the stroke. It is not difficult, however, to obtain a sufficiently accurate average value for both quantities.

The oil used to lubricate the valve was a high grade cylinder oil such as is regularly supplied by the Vandalia Railroad Company for use on its locomotives.

Fig. 38 shows sample indicator diagrams from the steam

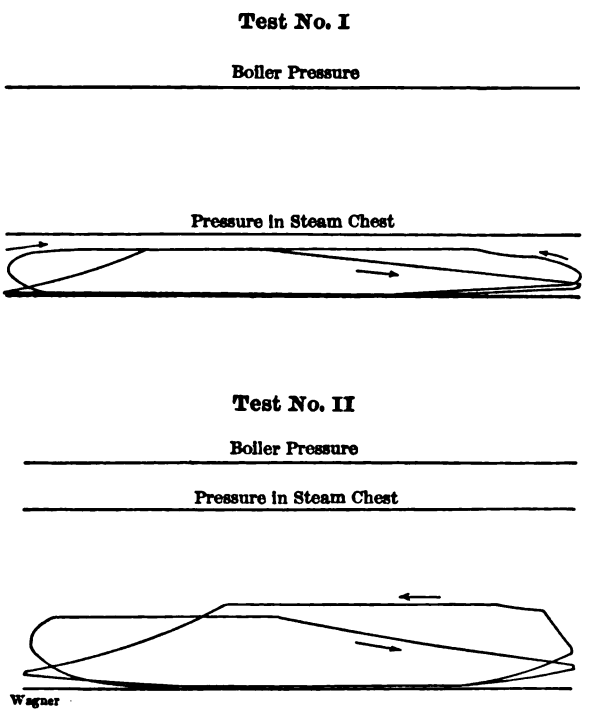


FIG. 38.

cylinder for each of the tests. Additional lines have been placed upon the diagrams, to show to the same scale the average boiler pressure and the average pressure in the steam chest during the tests.

The indicator diagram taken from the steam chest was substantially a straight line, showing that, with the valve speeds used, a constant pressure was maintained in the steam chest.

One interesting point disclosed by the indicator diagrams is the time required for the opening or closing of the ports to make itself felt upon the pressure in the cylinder. The distance on

the indicator diagram between closing to steam, and opening to exhaust, should be equal to the sum of the steam and exhaust laps—that is, one inch. The distances upon the diagrams vary from one and one-eighth to one and five-eighths inches, showing an appreciable lag between the actual closing and opening of the ports and the corresponding points on the indicator diagram.

It is to be kept in mind, however, that these indicator diagrams correspond with the motion of the valve, and not, as in the ordinary diagram, with the motion of the engine piston, and also that the piston remained stationary at the middle of its stroke.

DISCUSSION.

Prof. R. A. Smart.—Professor Wagner's paper is an interesting one, and the method adopted of determining the friction of a locomotive slide valve is new and ingenious. The friction of a slide valve upon its seat is greatly affected by the pressure in the cylinder. Other things being equal, the greater this pressure, the less will be the valve friction. It cannot be said, however, that this effect is a function of the mean effective pressure in the cylinder. For instance, the pressure in the cylinder during the period from admission to cut-off—that is, when the port is more or less open—has much less effect in relieving the friction of the valve than the pressure in the cylinder when the valve is covering the port. It will be remembered that the highest points in the ordinary indicator card occur when the valve is more or less open. Now, should these high points by any means occur when the valve is closed, the conditions affecting the friction of the valve would be quite different. In the tests under consideration it will be noted, from the cards shown, that during the period from cut-off to release the pressure remains the same as the highest pressure of admission, instead of falling away along the expansion curve as in ordinary practice. It seems to me that for this reason the tests under consideration do not fairly represent the conditions which obtain in ordinary service. The conditions which obtain in the cylinder from the point of compression to the point of admission tend to diminish the discrepancy. It should be further noted that the valve in question had a balanced area of about 58 per cent. of the Master Mechanics' recommended practice for balancing slide valves.

Assuming for the moment that the conditions in the cylinder were similar to those which obtain in practice, I cannot quite agree with the method adopted for determining the coefficient of friction. For instance, it has been assumed that the average net rubbing surface on the bottom of the valve and the rubbing surface of the packing strips are both pressed against their respective seats with a pressure per square inch equal to that existing in the steam chest. This would, of course, be true if the rubbing surfaces were in perfect contact and there were no leakage. It will readily be seen that should there be any leakage, as there generally is in service, the normal pressure per square inch between the rubbing surfaces is something less than the pressure of the steam in the chest, and may be much less than that. Under the assumption made, the packing strips in Test 2, with 122 pounds in the steam chest, would press against the balance plate with a total pressure of about 2,700 pounds, and with higher steam pressures this would be considerably increased. This, of course, is much greater than the pressure which actually exists between packing strips and balance plate. Again, it has been assumed that all of the power exerted by the motor was expended in overcoming the

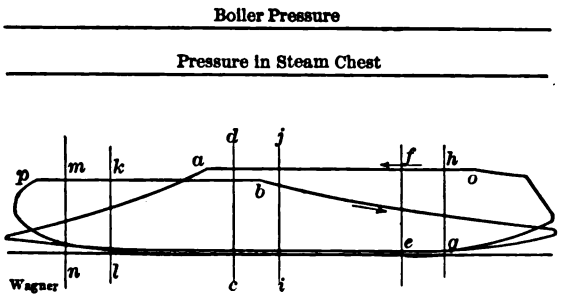


FIG. 38*a*.

friction of the valve. I believe, however, with the locomotive valve and valve gear as ordinarily made, and with the speed under which the tests were run, about 400 double strokes per minute, that a considerable part of the power of the motor was expended in overcoming inertia effects of the valve; that is, in producing acceleration and retardation. Theoretically, these two effects would balance each other, but to those familiar with locomotive running it is known that some of the power is

expended in additional friction caused by the springing of the parts.

In discussing the indicator diagrams presented, it is stated that they show a discrepancy between the actual point of exhaust opening and closure and that shown on the card; that whereas the distance between cut-off and release should be 1 inch, it measures on the cards from $1\frac{1}{8}$ to $1\frac{5}{8}$ inches. This is, I think, due to a misinterpretation of the diagrams Reference is made to Fig. 38*a*, which is a reproduction of the card taken from Test 2 in Professor Wagner's paper. Points *a* and *b*, which are about $\frac{1}{4}$ of an inch, or twice the inside lap, apart, are evidently points of release, and hence line *cd*, which is half-way between *a* and *b*, represents the mid-position of the valve. From this it would seem that the valve did not travel equally on both sides of its mid-position. Now, if *cd* be the mid-position of the valve, the position of the line and line point may be determined by laying off a distance equal to the outside lap, $\frac{7}{8}$ of an inch, on either side of line *cd*. This will give lines *ef* and *mn*. *e* and *m* are, therefore, the points of opening to steam, and *f* and *n* are the points of closing to steam. It will now be found that the distance from *a* to *f* and from *m* to *b* is about 1 inch, which, as Professor Wagner points out, should be the case. These measurements are not exact, because the card measures only $2\frac{1}{8}$ inches in length, whereas the valve travel was, I believe, 3 inches. The error in Professor Wagner's statement has evidently arisen from assuming points *o* and *p* to be the points of cut-off, whereas those points are really *f* and *n*. If the assumption that *cd* represents the mid-position of the valve is not correct, a similar line of reasoning can be followed out by adopting line *ij*, which is the mid-position of the diagram, as the mid-position of the valve. This would bring the points of cut-off at points *h* and *k*, instead of at *o* and *p* as assumed by Professor Wagner.

Prof. Wm. T. Magruder.—Any experimental data on the friction of slide valves is more than welcome on account of the present dearth of knowledge on the subject. It must be noted, however, that in the paper, as the "net horse-power consumed in driving the valve" is obtained by subtracting from the "average power delivered to the electric motor" the "power consumed in driving the motor and link-work," "after the valve stem was disconnected" from the rocker arm, the difference so obtained is the sum of the powers consumed in the friction of the slide

valve and the friction of the stuffing box, and not of the slide valve alone; and, second, that the stuffing-box friction varies with both the steam-pressure and the tightness with which the gland is screwed up. On the other hand, Table II. gives the horse-power consumed in driving the motor and link-work as 3.30 and 4.14 horse-power, which is not likely to be the case if the "valve stem was disconnected" from the rocker arm. If, however, the valve stem was not disconnected, but only the valve, and these figures were obtained by running the motor and link-work with the valve stem reciprocating through the stuffing box, the difference—.84 horse-power—would indicate the horse-power consumed in the frictional resistance of the stuffing box. If this is the case, the results would indicate that the coefficient of friction, μ, was inversely proportional to the square root of the steam-chest pressure, p, and that the average force required to move the valve was directly proportional to the unbalanced area, A square inches, and to the square root of the steam-chest pressure, p pounds per square inch; that is, that $\mu = \frac{c}{\sqrt{p}}$ and $F = \mu P = \frac{c}{\sqrt{p}} pA = \sqrt{p}\ A$, where c is a quantity which is .299 for Test 1 and $p = 42.18 \pm$ and $c = .386$ for Test 2 and $p = 122$. Taking, for example, a value of $c = .4$, with 196 $\pm$ steam-chest pressure, we might then expect to get an average stress in the valve rod of $F = c\sqrt{p}\ A = .4 \times 14 \times 124.95 = 700$ pounds and $\mu = \frac{c}{\sqrt{p}} = \frac{.4}{14} = .0286$.

It is also to be noted that the net power consumed in driving the valve is considerably in excess of the powers obtained in the tests on the Chicago, Burlington and Quincy Railroad.

Mr. George Schuhmann.—I wish to call attention to the fact that we have in our *Transactions* some interesting information on what the previous speaker calls the leakage of steam between the rubbing surfaces. I have reference to Professor Robinson's paper—"Back Pressure on Valves," vol. iv., page 150—in which he calls this pressure between the rubbing surfaces "the pressure of the creeping fluid." I have made some experiments with slide valves, the results of which agree closely with those given by Professor Robinson; however, instead of the formula given by him, I use a more simple one, by assuming that this pressure

of the creeping fluid is equal to the average pressure of the fluids on both sides of the rubbing surfaces; that is, if we have in the steam chest 100 pounds gauge pressure, and atmospheric pressure in the exhaust cavity, then the average pressure between those rubbing surfaces which are exposed to full pressure on the one side and exhaust pressure on the other side will average about fifty pounds per square inch. The author of this paper has evidently assumed that the rubbing surfaces are under full steam-chest pressure without making any allowance for this pressure of the creeping fluid, consequently the total pressure holding the valve down is taken too high and the coefficient of friction too low. I also wish to ask the author for some information about Indicator Card No. 2: the steam-chest pressure is only a few pounds below the boiler pressure, while the highest pressure in the cylinder is only about one half of the steam-chest pressure. Considering that the piston was blocked in its central position so that it could not move, and the valve opened wide to let steam into the cylinder, I cannot understand why the pressure in the cylinder should not come up to nearly the steam-chest pressure.

There are some other interesting papers about friction of slide valves in our *Transactions; e.g.*, "Description of a Valve Dynamometer" by Mr. Giddings in vol. iv., page 631, and "On the Distribution of Internal Friction of Engines" by Professor Thurston, vol. x., page 110.

Mr. G. M. Basford.—Professor Smart has said practically what I intended to say in regard to this paper, and I would like to emphasize especially his remarks with regard to the pressure under the valve. It surely would be very different if the piston and valve both were moving. Another criticism may be made in regard to the extremely high speeds mentioned in the paper. We are not given enough data about the engine to know the size of the driving wheels; but if the driving wheels were 66 inches in diameter, the speed would be 80 miles per hour to correspond with the test data. If the drivers were five feet in diameter, the speed of the engine would be 75 miles per hour. These speeds are very high for any engine, and probably much too high to represent the conditions of the engine used in these tests. Although we are not given very much information as to the size of the engine, judging from the valve it must be a very small one. Furthermore, the range of speeds is small. Doubt-

less the speed has an effect on the friction, and in order to ascertain what that effect is, it would be necessary to carry the experiment down to much lower speeds. The valve travel in this case is apparently three inches, and I would like to ask the author in closing the discussion to explain why it was so small and to ask his opinion as to whether that has not the effect of preventing the application of the results to actual practical conditions.

Mr. F. A. Halsey.—The members who are interested in this subject may be glad to learn of some very valuable experiments made by Mr. Aspinall, of the Lancashire and Yorkshire Railway of England, the results of which formed the subject of a paper presented by Mr. Aspinall to the Institution of Civil Engineers, which was republished in the *American Machinist* for January 19, 1899. A dynamometer was placed in the valve stem, which was cut for that purpose, and the experiments were made on the road under running conditions. They were made somewhat in the same way as the similar experiments of Mr. Giddings already referred to, and with great completeness. One curious thing about them is that they seem to contradict Professor Robinson's experiments which have been brought up. Mr. Aspinall made some modifications in his apparatus by which he could discharge the greater part of the creeping steam if it were present, and the result was that he found no difference in the friction of the valve under the two sets of conditions. The natural conclusion is that with the valve in motion the creeping steam does not exist. Professor Robinson's experiments were made with plates lifted off the seat, but with no sliding of the plate upon the seat. It is very curious to see, whatever the explanation may be, that Mr. Aspinall's experiments do not agree with Professor Robinson's. Mr. Aspinall calculates the load on the valve from the gross area of the valve, as does the author of the paper under discussion, but he finds a much larger coefficient of friction—.0878 for an unbalanced and .0919 for a partially balanced or relieved Richardson valve.

*Mr. Frank C. Wagner.**—Objection has been made by Professor Smart and Mr. Basford that the pressure in the cylinder during the valve friction tests was different from what the pressure would be under normal running conditions. While this is

* Author's closure, under the Rules.

true, the difference is not so great as might at first appear. The maximum pressure in the friction test card is much less than what the admission pressure would be under normal running conditions with the same valve motion and steam-chest pressure. The reason is that when steam is admitted to the cylinder under normal conditions the piston is at the beginning of its stroke and the volume into which the steam is discharged is substantially the clearance volume and is relatively small. Consequently the admission pressure in the cylinder drops only slightly below the steam-chest pressure. When the piston is blocked at the middle of its stroke, the volume to be filled by the entering steam is one half the stroke displacement plus the clearance. Consequently the pressure does not rise nearly so high, especially at so high a speed as that of the tests. This also answers the query of Mr. Schuhmann as to why the maximum pressure in the cylinder is so much less than that in the steam chest. With a three-inch stroke the valve does not open full, but only about one half.

For the engine to take the same amount of steam under running conditions as was used in the tests, the expansion curve should show a pressure at the middle of the piston stroke equal to the maximum pressure shown in the friction test. Hence, between admission and mid-stroke the pressure under normal conditions would be greater than in the tests, and between mid-stroke and release it would be less, so that the average effect will not be greatly different. Furthermore, in practice the effective upward pressure on the valve would vary according to the point of cut-off, and the values obtained in the tests are well within the limits of such variation.

Mr. Basford has inquired the reason for the high valve-speeds. The principal object of the tests was to analyze the action of a locomotive boiler, and driving the valve by an electric motor was an incident of the boiler tests. Only one side of the engine was used, and in order to imitate the action of the exhaust steam in producing a blast, it was necessary to drive the valve twice as fast as would correspond with the speed of the locomotive. It is to be noted, however, that while the number of strokes of the valve is unusually high the length of stroke is small, so that the linear velocity of the valve is not outside of the range of practice. The stroke of the valve was limited by the dimensions of the link motion and the available space beneath the locomotive for

placing the electric motor. The length of the valve stroke was not so great as when the valve motion is in full gear, but it corresponds to an intermediate position of the link, which is certainly one of the actual conditions met with in practice.

With regard to the creeping of the steam, Mr. Aspinall's experiments, quoted by Mr. Halsey, show that the effect is negligible when the valve is in rapid motion. Professor Robinson himself states in his original paper that when the plate experimented with was laid upon its seat it required from five to ten seconds for the air caught between the two surfaces to leak out. With a valve making a stroke in one fourteenth of a second, it does not seem probable that any considerable creeping of the steam can take place, and Mr. Aspinall's tests confirm such a view.

Professor Smart's interpretation of the indicator card does not differ materially from my own, and his figure illustrates exactly the point which I made. Referring to Professor Smart's figure, the point *e* is where the valve actually begins to open to steam, but the effect of the admission of the steam upon the pressure in the cylinder does not show itself until a point near *g* is reached. In the card from test No. 1, the distance between the apparent points of release is much greater than twice the exhaust lap. It is interesting to note that the cards taken by Mr. Aspinall show a similar effect, although less marked on account of the smaller speeds at which they were taken.

In calculating the coefficient of friction for the valve, the friction of the stuffing-box has been assumed to be negligible. During the tests the gland was eased off and the valve stem freely oiled.

Professor Magruder is mistaken when he assumes that the valve was disconnected from the stem in the second test, where the power used to drive the motor and link-work is given as 4.14 horse-power. In both cases the valve stem was disconnected from the rocker arm. In test No. 2 the increased power required to drive motor and link-work is due to an increase of the internal losses in the electric motor when working under a greater load.

In comparing the values obtained for the coefficient of friction with those obtained by others, due regard should be paid to the intensity of pressure between rubbing surfaces, the rate of feed of the oil, the velocity of rubbing, and the quality of

the lubricant. The oil used in these tests is known as "Galena" cylinder oil. In the tests referred to by Mr. Halsey, where the coefficient of friction was found to be .0878 and .0919, only four drops of oil per minute were fed to the valve, while in the tests under consideration twenty drops per minute and fifteen drops per minute were fed. The quality of the oil used may also have been quite different.

No. 834.*

PRESSURE IN PIPE DUE TO STOPPAGE OF FLOWING LIQUID.

BY GEO. M. PEEK, NEW YORK CITY.

(Junior Member of the Society.)

WHEN a liquid is flowing through a pipe there is a certain amount of energy in the liquid, and if we stop the flow this energy must be used up in some way.

If the liquid is incompressible, and we stop the flow suddenly, the energy of the liquid is used up in doing work on the pipe by stretching it or increasing its diameter.

If the liquid is compressible, the energy of the liquid is used up in compressing the liquid and stretching the pipe. Nearly all bursting of pipes is due to a sudden checking of the velocity of the liquid or to the freezing of the liquid.

First: Consider a case of instantaneous stoppage of an incompressible liquid. As stated above, in this case the energy of the liquid has to be expended entirely in stretching the material of the pipe. For this we have the following equation:

$$\frac{Av^2}{2g} \times \frac{d}{1728} = \frac{p^2DA}{24Et}.$$

In this,

A = area of pipe in square inches.
D = diameter of pipe in inches.
v = velocity of the liquid in feet per second.
E = modulus of elasticity of the material of the pipe.
t = thickness in inches (t must be small in comparison with D).

The above equation is deduced in the following manner:

$$E = \frac{\text{stress}}{\text{strain}} = \frac{\frac{pD}{2t}}{\frac{e}{\pi D}}$$

when e is the stretch of the pipe in inches.

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

$$E = \frac{p\pi D^2}{2et}; \text{ therefore } e = \frac{p\pi D^2}{2Et} \text{ in inches,}$$

or,

$$e = \frac{p\pi D^2}{24Et} \text{ in feet.}$$

The work done on the pipe by stretching it is

$$\frac{epD}{4} = \frac{p}{4} \times \frac{p\pi D^3}{24Et} = \frac{p^2 D\pi D^2}{4} = \frac{pDA}{24Et} \text{ foot-pounds.}$$

We multiply e by $\frac{pD}{4}$ because the final pull on one side of the pipe one inch long is $\frac{pD}{2}$ and the mean is $\frac{pD}{4}$. This supposes the initial pressure in the pipe is zero. If we have an initial pressure, as we will in most cases, then p is the increase in pressure above the initial.

The energy of the liquid is

$$\frac{Wv^2}{2g}, \text{ or } \frac{Av^2}{2g} \times \frac{d}{1728}; \text{ where } W = \frac{Ad}{1728},$$

d is the density of the liquid.

Since the energy of the liquid is expended in stretching the pipe, we have the equation given above.

Second: Consider the case of the instantaneous stoppage of a compressible liquid in an inelastic pipe. In this case the energy of the flowing liquid is expended entirely in compressing the liquid, and we have the following equation:

$$\frac{Av^2d}{2g \times 1728} = \frac{p}{2} \times \frac{p}{E_1} \times \frac{A}{12},$$

where E_1 = modulus of elasticity of the liquid.

This equation is deduced in the following manner:

$$E_1 = \frac{\text{stress}}{\text{strain}} = \frac{p}{e_1} \text{ or } e_1 = \frac{p}{E_1} \text{ in inches, or } \frac{p}{12E_1} \text{ in feet.}$$

The total final pressure over the section of the pipe is pA, with a mean pressure of $\frac{pA}{2}$; then the work done in compressing the liquid is $\frac{pA}{2} \times \frac{p}{12E}$, hence the above equation.

Now, combining the first and second cases, or where we have a compressible liquid flowing in an elastic pipe, the energy of the flowing liquid is the same; but it is expended in compressing the liquid and stretching the pipe, and we have the following equation:

$$\frac{Av^2}{2g} \times \frac{d}{1728} = \frac{p^2DA}{24Et} + \frac{p^2A}{24E_1},$$

or,

$$\frac{v^2}{2g} \times \frac{d}{72} = p^2\left(\frac{D}{Et} + \frac{1}{E_1}\right).$$

Now suppose that, instead of stopping the liquid instantaneously, it is stopped in a given length of time. If the liquid has a velocity of v and is gradually brought to rest, the mean velocity is $\frac{v}{2}$; and if the liquid is stopped in a time T, it will move through a distance $\frac{v}{2T}$. If p is the pressure tending to retard the liquid, or is the increase in pressure in the pipe, the work done will be $\frac{pv}{2T}$; or $\frac{Wv^2}{2g} = p\frac{v}{2T}$.

If we apply a force suddenly to an elastic body, the strain produced would be twice what it would be if applied gradually.

To find the total pressure in a pipe under a given head when the velocity of flow is suddenly stopped, we should find the increase due to sudden stoppage of the liquid, taking into account the compressibility of the liquid and the elasticity of the material of the pipe; then add to this the static pressure already in the pipe, also a pressure equal to twice the velocity head and friction head.

On page 117 of "Barr's Pumping Machinery" he adds 147×2, or 294. This is not correct, because a part of this pressure is a steady pressure, and is exerted on the pipe while the water has a velocity of 5 feet per second. The pressure which is suddenly applied is that due to a velocity head of 5 feet per second, and the friction head.

This discussion would not hold for gases, on account of the appreciable increase in temperature caused by compressing the gas.

DISCUSSION.

Mr. Wilfred Lewis.—The fundamental principle enunciated at the beginning of this paper, that the energy stored in a flowing liquid must be used up in some way when its motion is arrested, cannot be questioned, but the analysis offered requires explanation and confirmation as far as possible by experiment.

In the first place, the symbols used are not all clearly defined, their meaning being left to inference from the context instead of being definitely stated. For example, d is said to be the density of the liquid, but it is only from the context that the value of d appears to be rated in pounds per cubic foot. The increase in pressure, p, due to stoppage of flow, might be taken anywhere in the length of pipe under consideration; but since increase at no particular point is mentioned, it must be inferred that p is the maximum increase in pressure, or the increase at the point of stoppage. This pressure is, however, treated as uniform over a length of one inch, and to reconcile the proposed formula with the explicit meaning given to some of its symbols, it is necessary to assume that the analysis is based upon the somewhat peculiar conception of a pipe and liquid column one inch long, because any other assumption leads to an absurdity.

For instance, in the expression $W = \frac{Ad}{1728}$, we have by transposition $d = \frac{1728\,W}{A}$, and if W were the weight of liquid in a pipe of indefinite length whose area of cross section was A, it would appear that the density of a liquid depended upon the size of the pipe in which it was carried. W, the weight of liquid, must therefore be intended only for a column one inch long, and A, the area of cross section, must sometimes be used in the sense of cubic contents. If these inferences are correct, it must then be inferred from the omission of any reference to length of pipe that the pressure in question is not affected thereby.

Upon reflecting that the quantity of elastic material capable of storing energy increases directly as the quantity of fluid in motion, it is quite possible to believe that the length of pipe may be omitted as a factor of no import in the final result; but a broad generalization like this would seem to be worthy of

definite statement and proof. And yet, whatever the length of pipe may be, it is perfectly clear that the maximum pressure will be developed at the point where stoppage of flow takes place, and that from there back to the inlet the pressure will gradually reduce to zero.

If this diminution of pressure is uniform, as seems probable from the nature of the case, the problem may thus be solved:

Let l_1 = length of pipe in inches.
l = length from inlet to any point under consideration.
P_1 = maximum pressure at point of stoppage.
P = pressure at any point, l, from inlet.
$C = l_1 A$ = contents of pipe.

The energy of the liquid is $\frac{Cv^2d}{2g \times 1728}$ foot-pounds, and in the first case considered this must be equal to the energy received by the pipe in stretching. At any point, l, from the inlet, the pressure $p = l\frac{P_1}{l_1}$, and in a length dl, at this point, the energy received by the pipe must be

$$\frac{P^2DA}{24El}dl = \left(\frac{P_1^2DA}{l_1^2 24El}\right)l^2dl.$$

Integrating, the total energy received by the pipe becomes

$$\frac{P_1^2DAl_1}{72El} = \frac{Cv^2d}{2g \times 1728} = \frac{l_1Av^2d}{2g \times 1728}.$$

Therefore $\frac{v^2d}{2g \times 1728} = \frac{P^2D}{72El}$, and, on the basis assumed of uniform variation in pressure from inlet to point of stoppage, it thus appears that the pressure due to stoppage must be $\sqrt{3}$ times as great as given in the paper. Similarly, for a compressible liquid in an inelastic pipe, it will be found that

$$\frac{v^2d}{2g \times 1728} = \frac{P_1^2}{72E_1},$$

and for the normal condition of a compressible liquid in an elastic pipe we have

$$\frac{v^2d}{2g \times 1728} = \frac{P_1^2D}{72El} + \frac{P_1^2}{72E_1};$$

or, using P in the sense of P_1 as taken in the paper, and reducing, we have

$$\frac{v^2 d}{2g \times 24} = P^2\left(\frac{D}{Et} + \frac{1}{E_1}\right).$$

The compressibility of water being about 100 times as great as that of iron or steel, it follows that in ordinary wrought-iron pipes the pressure due to a sudden stoppage of flow might be approximately expressed by the equation, $P = 110v$, when, as in the present case, no account is taken of a possible increase in length of pipe. The subject is one of great interest and importance, but in actual practice the problem is generally more complex than is here assumed, and it may be questioned whether in most cases it can be brought completely within the power of analysis. In a system of pipes of various diameters, connected with valves, cylinders, and receivers, the length of each section of pipe can no longer be neglected, and friction also appears as an important element in the determination. The analysis should, however, begin with a straight pipe of uniform section, and for this simple case there is still room for investigation of the law by which the pressure must vary toward the point of stoppage. The assumption of a uniform pressure throughout the pipe is clearly inadmissible. It must vary from nothing at one end to a maximum at the other, but whether directly as the length or as some other function thereof I am not yet prepared to say; though, I believe, the truth cannot be far from the direct proportion which I have assumed. Possibly, however, the maximum pressure at every point in an extended length of pipe may not be attained at the same instant, and thus waves of pressure may be set up, or the law of variation in pressure may be such that the neglect of the length of pipe, as tacitly avowed by the author, is not strictly allowable. It must also make a difference whether the pipe is fixed, or free to expand in the direction of its length, and although further analysis may do much toward the complete solution of the problem, experimental confirmation is always to be desired.

*Mr. Peek.**—In the expression $W = \frac{Ad}{1728}$, W is the weight of the liquid in one inch of the pipe, d is the weight of one cubic foot of the liquid.

* Author's closure, under the Rules.

Each inch of the pipe is supposed to take up its share of the energy of the liquid, and that being the case, the length of the pipe would not appear in the equations.

Of course the analysis given is not intended for a complete discussion of the subject, because a full solution of the problem is much more complicated than the solution given.

The object of the paper was to give a simple approximation for use in designing hydraulic rams.

No. 835.*

A BROKEN FLYWHEEL AND HOW IT WAS REPAIRED.

BY JAMES MCBRIDE, BROOKLYN, N. Y.

(Member of the Society.)

THIS wheel was one of the band wheel type, weighing between 30 and 40 tons, was driven by a pair of Corliss engines 30 inches in diameter by 60 inches stroke, and ran 53 revolutions per minute, carrying two double leather belts, one 48 inches wide and one 34 inches wide. The rim was composed of ten ribbed segments attached to the arms at the centre, and bolted together at their ends between the arms, each arm carrying one segment. The construction of these segments will be understood by referring to Figs. 42 to 47, of which 43 and 45 are views of each half of the wheel spread out flat and looked at from the inside.

Four of these ribs, each 5½ inches deep by 1¼ inches thick, run around inside the rim, and are intersected at right angles by other ribs across the rim. Those at the ends of the segments making the flanges are 1½ inches thick, and those extending out from the arms are 2 inches thick.

The segments are bolted together with six 1⅛-inch rough bolts in a cored hole 1⅞ inches in diameter, and through each pair of flanges there are two ⅝-inch steel dowel pins. The segments are secured to the arm flanges by four 2¼-inch bolts, and the arms are secured to the hub, each with two 2¼-inch bolts through the hub flanges.

It will be noticed by reference to Fig. 41 that there are really three wheels in the width of this broad rim (90 inches), and that only the centre one, 37½ inches wide, gets any material support from the arms.

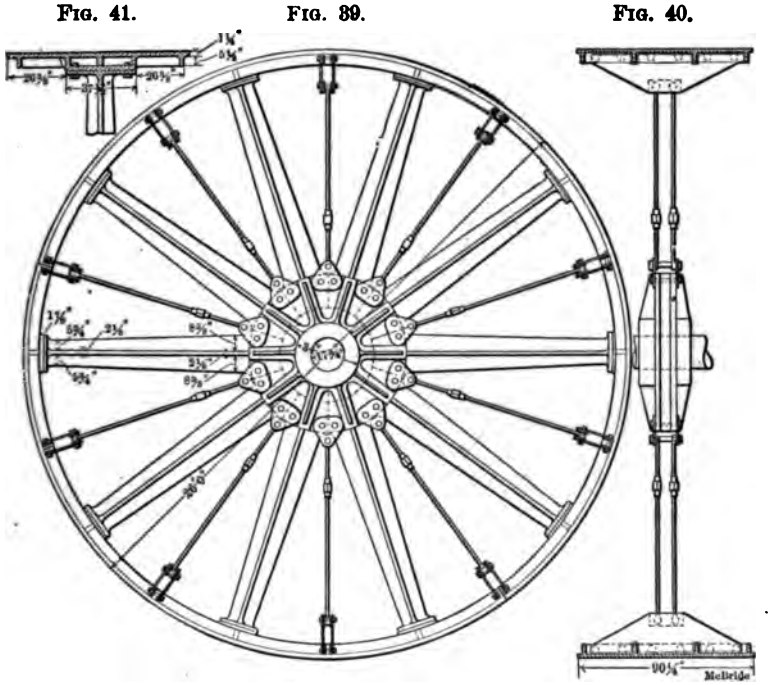
As this was the method of building broad-rim band wheels some years ago, and as there may be others who are troubled with the fear of such wheels going on a "bust," the writer, for

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Vol. XXI. of the *Transactions*.

the benefit of such, has decided to tell how he repaired this one that was badly broken. The wheel was erected early in 1885, and ran until 1889, when an accident to the governor permitted the engines to run away with it. It is not known what speed they reached, but it was found upon examination that a number of cracks had appeared in the ribs, located as shown by the crosses (x) on Figs. 43 and 45.

There were thirty-one of these cracks, and it will be noticed

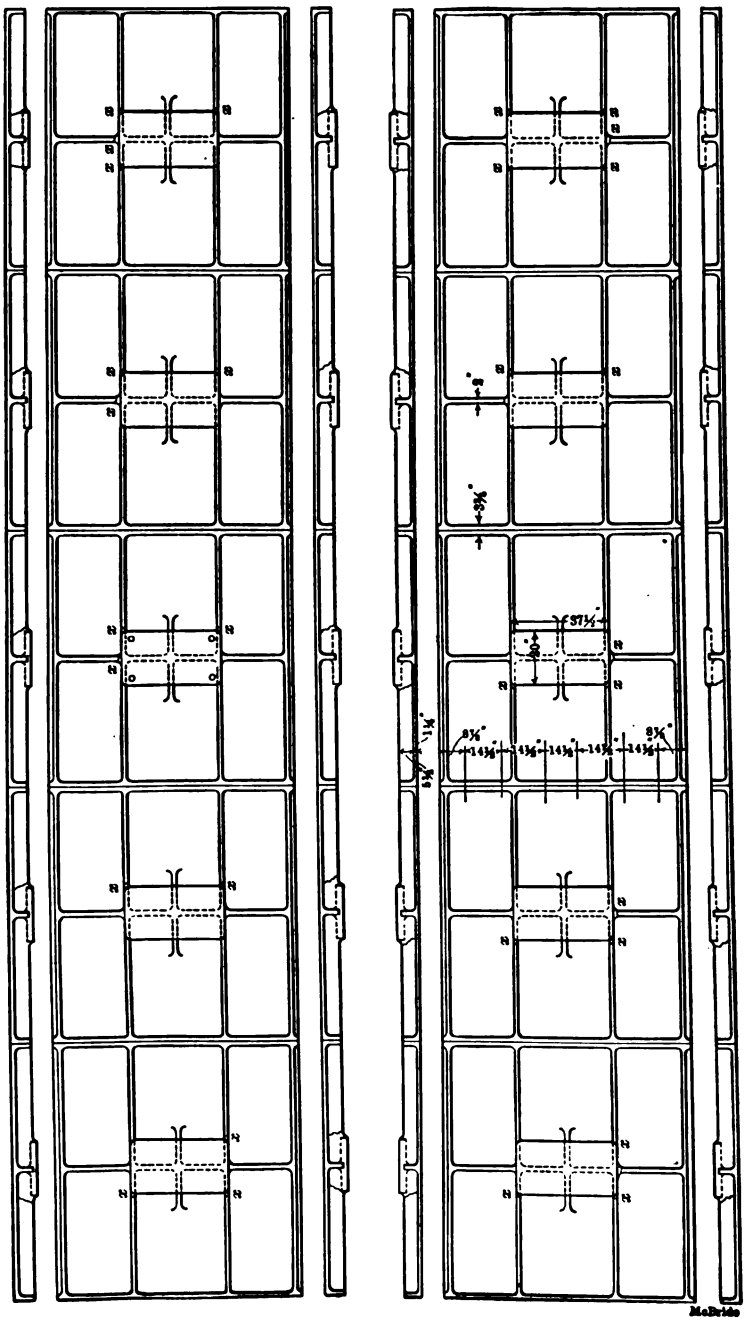
FIG. 41. FIG. 39. FIG. 40.



that they are all located around where the segment is bolted to the arms. It has been suggested that some of these cracks may be due to shrinkage of the castings, but out of more than two hundred other places on the castings where such shrinkage could occur, not one is to be found, nor were there any in the castings anywhere when the wheel was erected.

It therefore seems that these cracks must have been caused by the strains on the metal when the engines ran away, by reason of that part of the rim between the arms being forced out by centrifugal force due to high velocity, as this is just what would occur under such conditions.

FIG. 42. FIG. 43. FIG. 44. FIG. 47. FIG. 45. FIG. 46.



Careful examination of these cracks during the last ten years did not show that they were extending, but the surface of the rim running out of true, and this untruthfulness being very much increased by increased speed of the engines at times when all the work was thrown off, it was determined to strengthen the wheel and, if possible, restore it to its true running condition.

As the wheel was in service twenty hours of the twenty-four, each six days of the week, and as business would not permit a long stoppage, the writer devised the method here described:

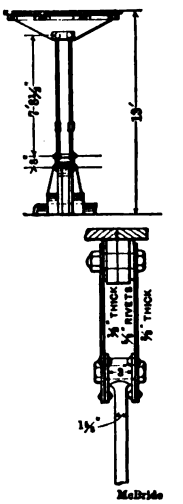


FIG. 56.

Fig. 39 is a side elevation of the wheel; Fig. 40 is a cross section near where the segments are bolted together, and Fig. 41 is a cross section of the rim near the arm; Figs. 47 to 42 are flat and edge views of the rim, while the rest of the figures are details of the different parts on a larger scale. After completing the designs, it was thought best to submit them to some expert engineers in this line before proceeding with the work. Mr. Albert A. Cary, of this city, and Mr. James B. Stanwood, of Cincinnati, O., both members of this Society, were employed to examine and report on the case. They reported that the method submitted was the best one that could be used, and with certain modifications would make the wheel perfectly safe. Among their suggestions were the following:

1st. That the bolts for bolting the rim flanges together be enlarged; that the holes in the castings be reamed, and turned bolts used.

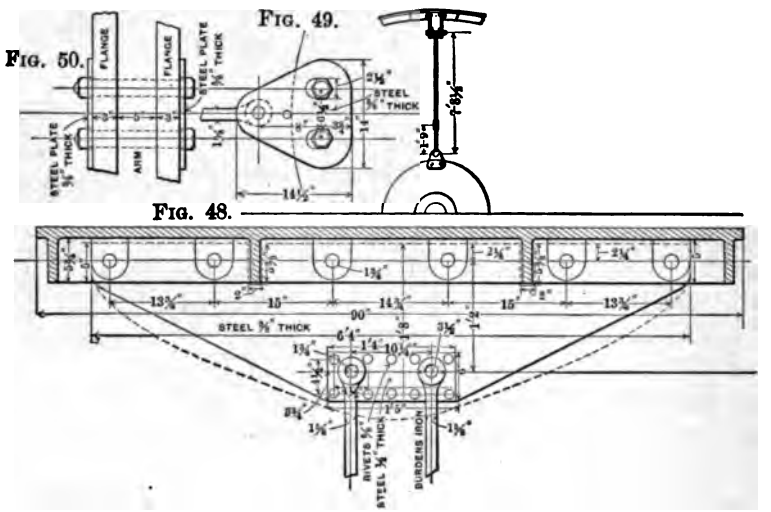
2d. That the outside steel-flange plates should be made a true parabola, as shown by the heavy dotted lines on Fig. 48.

3d. That the tie rods take hold farther from the edge of the plates than was shown on the design.

The latter suggestion was adopted. The first one involved so much extra labor and expense, and the benefit to be gained was so small, that it was not followed, the method described and shown in Figs. 54 and 55 very nearly accomplishing the same result. The second suggestion would probably have been followed, only that it involved cutting away of much more of the engine-room floor (which is iron) and the removal of the railing

around the wheel; hence it was decided to use plates of the shape originally shown.

It was determined to fasten the segments to the hub of the wheel by means of flat steel plates $\frac{5}{8}$ inch thick, one bolted on each side of the flange where the segments are connected, and by two iron tie-rods with turn-buckles, and triangular plates fitted over the heads and nuts of the bolts, binding the arms to the hub. Figs. 48, 49, and 50 show the details of the fastenings to the hub and rim, while Figs. 51, 52, and 53 show details of fastening the tie rods to the plates. Figs. 54 and 55 show method of fastening those plates to segment flanges by rough bolts.

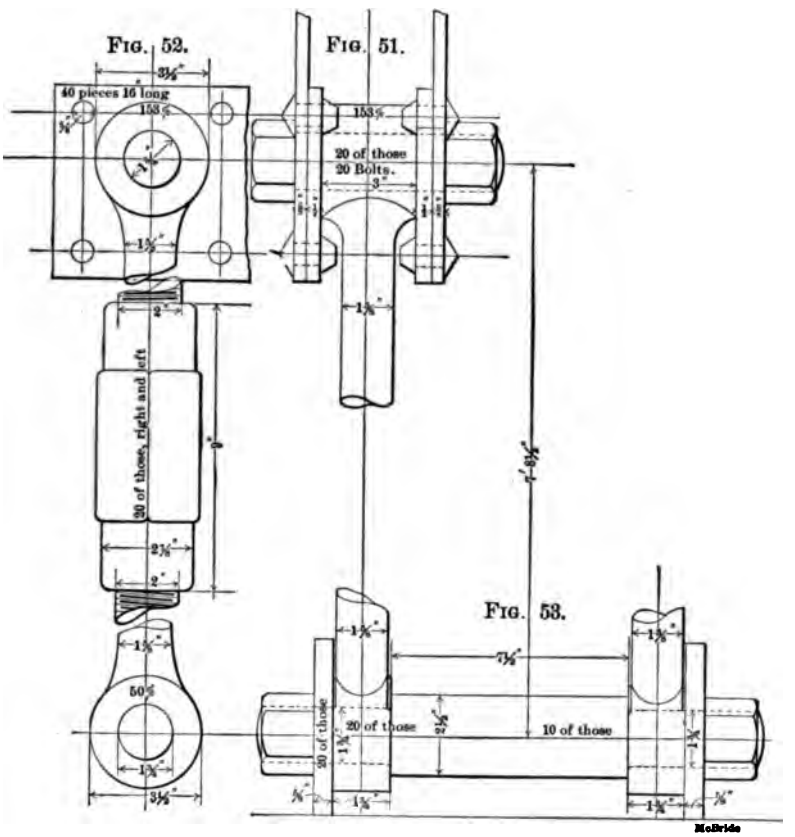


This last-mentioned detail was a very important one, on account of a rough bolt not fitting a rough hole; and as it was deemed impracticable to ream those holes and put in a turned bolt, the following method was employed to get a complete metal bearing on the tie rods from the hub to the rim:

The bolts were removed from the segment flange, one plate laid to its place, and the holes marked on it $1\frac{7}{8}$ inches in diameter. The holes through the steel plate were to be only $1\frac{3}{4}$ inches in diameter, and were not drilled in the centre of the marking, but so that the edge of the hole touched the side of the marking next to the centre of the wheel, so that when the bolt was put in place it had a bearing on the flange next the centre of the

wheel and on the plates next the rim. This left no lost space to be taken up when the tie rods were tightened.

The triangular-shaped pieces (Fig. 49) were punched so that they slipped neatly over the heads and nuts of the bolts on the hub, and marked and fitted close to the sides next the shaft. These plates were fitted in pairs, and held in place by a $\frac{3}{4}$-inch



bolt passing through them just outside of the hub flanges. After being thus fitted and held in place, the centre of the bolt holes for the ends of the tie rods were laid off by correct equal measurements from the centres of the flange bolts and from the side of the shaft.

These plates are held apart by a separator $2\frac{1}{2}$ inches in diameter, with the ends turned down to take the eyes of the tie rods and plates, and are held by nuts on each end, as shown in Fig. 53.

The outer ends of the tie rods are secured to the steel plates at the rim by eyes and turned bolts, as shown in Fig. 48, the holes being reënforced on the inside of the plate by smaller plates ½ inch thick.

One plate of each pair at the rim was marked from segment flange and its mate bolted to it, and both drilled together.

To mark off this work, and to put it back in place when finished, advantage was taken of the hour four times a day when the engines were stopped, the parts on the hub being put back as they were finished, until all with the short ends of the tie rods were in place, these parts being so light and near the centre of the wheel as not to throw it materially out of balance.

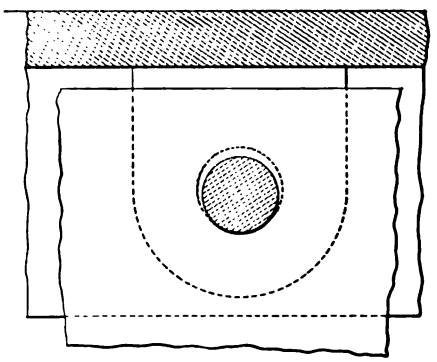


FIG. 55.

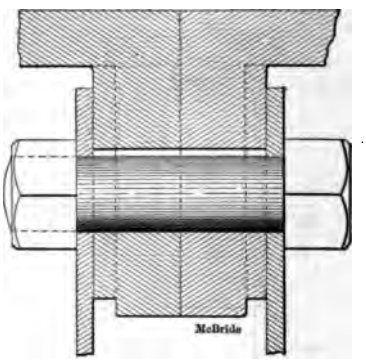


FIG. 54.

A different method, however, had to be adopted with the parts which were attached to the segments. These were fitted in pairs diametrically opposite on the wheel, and when ready were put in place in this order, thus always keeping the wheel in balance:

After all the parts were in place and the tie rods slightly tightened, a surface gauge was placed on the floor somewhat below the centre of the shaft, with the pointer touching the rim opposite the tie rods. The wheel was then turned until the end of the nearest arm came opposite the pointer; the distance between the end of the pointer and face of wheel was noted, and the wheel turned back to its first position, and the tie rods tightened until the noted distance appeared between the pointer and wheel. Each part opposite the tie rods was thus treated, and the wheel gone over twice, when it was found that the rim, from

the centre out toward the edge as far as it was supported by the flange on the arm, ran as true as when the wheel was erected, and on the edges of the rim where the plates took hold, nearly so; while the edge of the rim out from the arms did not run true, because the cracked ribs at those points allowed the rim to spring out, and could not be brought back by the tie rods.

Nothing has been said about calculating the strength of the various parts, but they were all based on the assumption that all that part of the rim lying between any two arms was entirely broken loose from the rest of the rim, and its centrifugal force at normal speed held by the two tie rods. These tie rods were of dimensions to sustain this load with a factor of safety of nearly 5 to 1, and the strength of all other parts was based on this factor. The total weight added to the wheel was about 3,700 pounds, and the total cost of repairs, labor, and material less than $500.

For the method of attaching the triangular plates to the hub of the wheel by fitting over the heads and nuts of the flange bolts, and for the separator for holding plates and tie rods, I am indebted to Mr. John Young, of Watts-Campbell Engine Co. of Newark, N. J.

To my foreman machinist, Mr. E. H. Thomas, I am also indebted for many valuable little kinks which have done much to further the work, and in conclusion I will say that the wheel is now stronger than when first erected; that it was not touched with the edge of a chisel nor the point of a drill, and that not a working hour of the engines was lost during the repairs.

DISCUSSION.

Professor John E. Sweet.—I am very much pleased with a paper which gives an account of a failure, for if we would all tell of our failures it would be doing others as much good as to tell them of our successes. I have had some sad experiences with flywheels, except that no one was injured—sad financially; and it was wholly due to what Mr. Porter pointed out—internal strains in casting. We had peculiar ones to cast which had very heavy bosses, much heavier than the rims, and we had learned to cast these wheels successfully without any internal strain whatever, notwithstanding the difference in the

body of metal. But it fell to our lot to make a different wheel, in which we thickened up the ring about fifty per cent., forgetting all about what we had learned in casting the other wheels and treating this new wheel in exactly the same way. As a result, we had an excessive strain in the rim—we broke up about a dozen afterwards—so that the instant we would strike a rim with a sledge it would pop open for about a quarter or half an inch. That simply emphasizes what Mr. Porter has said, that the trouble is with the internal strains in cooling the casting, for there is no trouble from centrifugal force.

There has been some discussion heretofore about where to part the rim in the wheel. So far as pulleys go, there is one right place and no other, and that is to split one of the spokes, or the two opposite spokes, clear through and bolt the spokes and the rim together. Then you have a half-spoke to support the outer end of half a rim, precisely the same at the point where your joint is as you have in the other part of the wheel. There is nothing to do but make the joint as strong as the rest of the rim, and you have as perfect a wheel as you can have, as all internal strains are avoided.

Mr. Francis H. Boyer.—From the standpoint of an engineer and not a constructor, I have had the privilege—I will not say the pleasure, but the privilege—of seeing several broken flywheels, and I have also seen flywheels of all kinds of construction that have lasted the life of an ordinary man. Wherever I have seen a broken wheel, it has been the fault of a foundryman. We go back to that disastrous wheel we have talked so much about, at Manchester, N. H. That wheel I should judge had nearly a 48-inch face; it was 24 feet in diameter. The defects in casting equalled fully 60 per cent. of the restraining strength of metal, due to bad work in the foundry. I received a short time ago some large pulleys for a fast speed, and one of my young men came to me and said, "Come here"; and he took his knife out and dug a three-quarter-inch hole of putty in the centre of one of the arms. I had him keep at that, and he found those defects all over the wheel. We see fly-wheels of all kinds of construction which have lasted for years on engines which have run away, which we would consider were weak, and they stand all right. I do not know but that I am ready to put the foundrymen to the rack, and not the designer.

Professor Lanza.—I should like to say that too much cannot

be said about the bad casting of the Amoskeag wheel; but even if the casting had been good, the design was very poor indeed, and the stresses were not provided for at all as they should have been.

Mr. James McBride.—I would advise those who contemplate repairing a broken wheel—I speak with reference to my wheel—to use iron tie-rods instead of steel. My first thought was to use steel tie-rods, but on account of the shape of the ends it was necessary to make two welds in each rod, and I could not find a blacksmith who would guarantee to weld steel rods and be sure they would be perfect. With iron there was no trouble, so I increased the size of the rod an eighth of an inch and used the best wrought iron I could get. In regard to Mr. Frith's wheel I have only a word to say: if it were possible to carry the belt on the end of the arms of a flywheel we would then have just two things to take care of—a beam fixed at one end and loaded at the other, and the centrifugal force of the material in the arm itself. When the arm is made strong enough to withstand the strain of the belt, the centrifugal force of the material in the arm may be entirely disregarded: we would then have only the beam fixed at one end and loaded at the other to take care of. As it is impracticable to carry the belt on the ends of the arms, we must have a rim. It seems to me that Mr. Frith's design is a step in advance in flywheel design. He endeavors to eliminate all the weight possible between the points of the arms and to put it at a place near the points of the arms to support the centre, making it as light as possible between the arms consistent with strength and putting the metal for the support of the rim where it ought to be.

Mr. H. H. Suplee.—The discussion on steel flywheels reminds me of some wheels I had to do with a number of years ago. These were not exactly flywheels, although they acted as such; they were the wheels of large band-saw mills. The speeds were high, 8,000 or 9,000 feet a minute, or revolutions of 350 to 300 for 8 and 9 foot wheels. At first such wheels were made of cast iron, but they soon went to pieces. These were then replaced with wheels with wrought-iron rims and wrought-iron spokes. With these the same action took place of which Mr. Frith speaks—that is, that they bulged out between the arms. This was remedied by putting in more arms, and by the number of arms being increased until the ends of the spokes were so close

together that there was no appreciable distortion and the wheels ran true, as was necessary for a band saw. Instead of changing the section or changing the shape, we simply supported the rim, and those wheels are running to-day, and running very successfully.

Mr. William Sangster.—While not exactly in the line of flywheels, a bit of high-speed experience with a disintegrator may prove of interest. The machine consists of two plates, each containing several rows of pins, one or two of which are

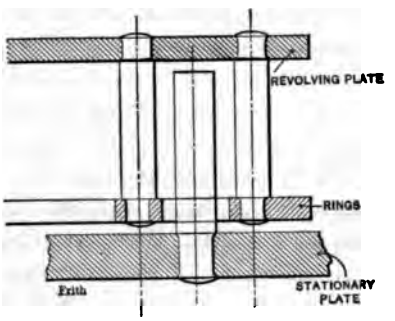


FIG. 57.

shown in the accompanying sketch. One of the plates is revolved in one direction, while the other either remains stationary or is revolved in the opposite direction. The pins in the revolving plates are secured at the outer ends by rings, one for each row. These rings prevent the pins from being thrown out by centrifugal force, and place each pin in the position of a beam secured at each end and uniformly loaded. Friable materials fed in at the centre are thrown out at the circumference in a powdered form. In this particular case the machine was used to grind gelatine as prepared for culinary purposes, and was speeded as high as we dared run it; that is, about 2,800 to 3,000 revolutions per minute. The outer row of revolving pins was spaced on a 26-inch circle, and as nearly as we could tell, estimating the pins as beams secured at each end and uniformly loaded, the stresses at the smallest sections were about 23,000 pounds per square inch. While these stresses are high, yet the machine has done good work for eighteen months, and apparently will continue so to do. Some idea of the value of the rings as supports for the pins may be had from the fact that

in larger machines running at slower speeds an occasional piece of iron has been accidentally fed into the machine with no further damage than one or two broken or bent pins, the rings and the rest of the pins remaining intact.

Mr. A. H. Raynal.—I would like to call attention to the fact that during this entire discussion one factor in the construction of wheels has not been brought forward, and that is the question of workmanship. Bad castings, of course, are very important in a flywheel, especially in the larger wheels. But in the larger wheels the question of the workmanship is almost more important than the design. I recollect about a year ago being called on as an expert in a case where a flywheel had broken in a rolling mill. The design of the wheel was good, the proportions were good, the castings were excellent; but when we came to investigate closely, the wheel being a "built-up wheel," we found that the arms had been fastened to the hub by bolts, rough bolts in rough holes nearly a quarter of an inch loose—no fit at any point—so that the rim and the arms could travel between the two hubs. What factor of safety did you have there?

It is certainly very pleasing to have such a master of mathematics as Professor Lanza tell us that the strains are so complicated that it is almost impossible to approach by mere calculation any factor of safety. It seems to me that the construction of flywheels is very akin to a subject which we had some time ago. Our discussions seem to run in grooves. It is now flywheels. A few years ago at the Cincinnati meeting it was chimneys, and, as you will recollect, as we passed through the soap works, and looked at that wonderfully high and beautiful chimney, one of our party said: "Mr. Borden, you have built more chimneys than anybody else. Do you follow Mr. Kent's formula, or do you follow Mr. Gale's formula." And Mr. Borden said: "Well, I generally look and see what kind of a chimney I constructed last, and then I make it ten feet higher and a foot or so larger in diameter" (laughter). So it seems to me that in our flywheels, especially with the large wheels, we have to employ a certain construction factor. It has been my good fortune to repair more than once flywheels of 24 to 30 feet in diameter which have been cracked mostly at the rim, employing similar means to those employed by Mr. McBride. There, however, we always took the greatest care to use turned

bolts in reamed holes, and if you recollect the dimensions of the piece of casting which you put into a wheel 30 feet in diameter, how difficult it is to plane it up, to fit it to the arms, to fit these to the rim and hub, it is almost impossible to say what the strains are in a wheel before ever it turns round the first time.

No. 836.*

A NEW GRAPHICAL METHOD OF CONSTRUCTING THE ENTROPY TEMPERATURE DIAGRAM OF A GAS OR OIL ENGINE FROM ITS INDICATOR CARD.

BY HENRY T. EDDY, MINNEAPOLIS, MINN.

LET the heavy line shown in Fig. 58 be the indicator card of a gas or oil engine. This card was, in fact, copied from a report of tests upon a Diesel oil engine by Prof. James Denton, of Stevens Institute, dated September 1, 1898, in which OV is the line of zero pressure, and OP of zero volume. The scale of pressures is such that the greatest pressure is 534.7 pounds absolute, as shown on the vertical at A.

Assuming that the contents of the cylinder follow the law of perfect gases sufficiently for practical purposes, we have the well-known equation

$$pv = ct, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which p, v, and t designate respectively the absolute pressure, total volume, and absolute temperature of the whole or any given part (for example, 1 pound) of the contents of the cylinder at any instant during the stroke, while c is a constant, different for each kind of gas, but invariable during the stroke for gas of given chemical composition.

Now at any assumed series of pressures such as $p_1, p_2, p_3, \ldots p_n$, we have

$$p_1v = ct, \quad p_2v = ct, \quad p_3v = ct, \quad \text{etc.} \cdot \cdot \cdot \quad p_nv = ct \quad . \quad (2)$$

In case absolute temperatures be plotted as ordinates in the same manner as pressures have been, and OV be taken as the zero line of temperatures as well as of pressures, it is evident that equations (2) represent straight lines through the origin having the slopes c/p_1, c/p_2, c/p_3, etc. . . c/p_n. On some convenient vertical, at A say, assume heights $p_1, p_2, p_3, \ldots p_n$. It

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

is convenient to make $p_1 = \frac{1}{2} p_2 = \frac{1}{3} p_3$, etc. $= \frac{1}{n} p_n$. Then the straight lines from O through the points 100, 200, 300, etc., are lines of equal pressure, taking the volumes and temperatures as coördinates. It will then be possible to construct as many points as may be desired upon a volume temperature diagram; for at any assumed pressure level p, the corresponding temperature level must be found at the same volume. For example, consider the horizontal pressure level 200; it cuts the indicator

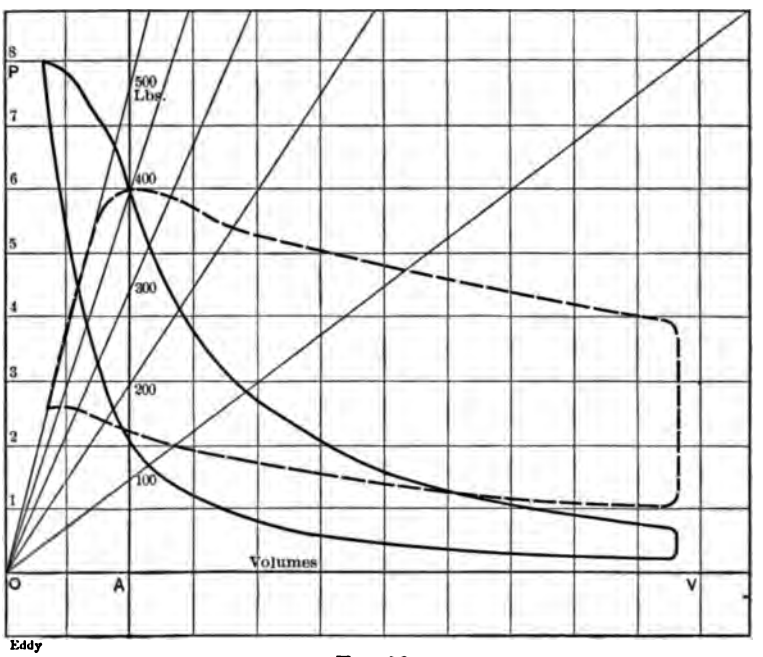


FIG. 58.

card twice, once at the right side and once at the left side of the vp card. The point of the vt diagram corresponding to that on the right side of the indicator card will be found on the line O 200 vertically above this right-hand point, and the point of the vt diagram corresponding to the point on the left side will be found vertically below it on the line O 200, and similarly for other points. The broken line in the figure is the vt diagram drawn through points constructed in this manner. This vt diagram represents just as truly the thermodynamic relations in the gaseous cycle as does the ordinary vp card from which it was derived.

It would be equally possible to construct by a like method a *pt* (pressure temperature) diagram to express the thermodynamic relations in the cycle.

It will be noticed that the lower side of the *vt* diagram corresponds to the lower side of the *vp* card, and that during compression the temperature rises until it is some two and a half times the absolute temperature at the beginning, with indications, since this side is nearly horizontal at its highest point, that further compression would raise the temperature no more; *i.e.*, the cylinder walls cool the compressed air (at the slow rate at which the piston is then moving) as rapidly as the compression heats it. In this engine the combustible is then forced into the cylinder during the first part of the expansion, while the temperature rises very quickly to a maximum, and after that falls in much the same manner as it rose during compression until the release is reached, when there is a sudden fall of temperature.

The point A is so taken in this figure that the *vp* and *vt* diagrams intersect near the maximum value of t, and is so taken for convenience in controlling the vertical dimensions of the *vt* diagram. In some parts of the construction just given the intersections by which points of the *vt* diagram are to be determined are at angles so acute that it is difficult to avoid inaccuracies, and a check upon the work is of importance. Such a check is found as follows: Consider the two pressures and temperatures at any assumed volume v, then, by equation (1),

$$\frac{pv}{t} = c = \frac{p^1 v}{t^1}, \text{ therefore } \frac{p}{p^1} = \frac{t}{t^1} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In other words, at any given volume v, the two ordinates or temperatures of the *vt* diagram have the same ratio as the corresponding ordinates or pressures of the indicator card. Thus, for example, wherever the upper sides of the *vt* and *vp* diagrams intersect, the lower sides should intersect at the same volume; *i.e.*, upon the same vertical. In case the construction is made upon squared paper (as it should be), the verification of the accuracy of the construction by equation (3) is readily effected at any volume by drawing a pair of lines from O through the upper extremities of the ordinates p and p^1, and finding whether the points on the respective lines at the levels t and t^1 are on the same vertical. Instead of using this as a test, one side

of the *vt* diagram may be constructed from one already constructed. The lower side is the most difficult to construct with accuracy, and it may be found by this method of similar triangles, or simple proportion from the upper side, more accurately than it is usually possible to construct it directly.

The *vt* diagram may be made to give the relative temperatures of the different points of the cycle with sufficient accuracy. But the actual temperatures in degrees Fahr. can only be known exactly in case it is possible to determine the actual temperature at some one point of the cycle. That cannot usually be determined with any great accuracy. Whatever may be the temperature of the air admitted to the cylinder, it becomes heated to an unknown amount before the admission valve closes, so that its temperature is uncertain. Again, the temperature of the exhaust at atmospheric pressure is frequently known. In Professor Denton's tests the temperature of the exhaust was usually 740 degrees Fahr. at full load, but that does not enable us to know the temperature of release with certainty. Fortunately, relative temperatures to any arbitrary scale are all that is necessary for the construction of the *et* (entropy temperature) diagram, and for the determination of the efficiency of the cycle.

If we should assume the air in the cylinder of the Diesel engine to have a temperature of 100 degrees Fahr. at the beginning of the compression (a temperature much too low, since the air in the engine-room was 100 degrees Fahr.), then it rises during compression to nearly 900 degrees Fahr., and to more than 2,700 degrees Fahr. at the maximum, and is still at more than 1,600 degrees Fahr. at release.

It should be carefully noted that corresponding points in the *vp* and *vt* diagrams are necessarily upon the same verticals—*i.e.*, have the same volume—and that the two temperature ordinates at any volume are proportional to the two pressure ordinates, as was shown by equation (2), but the ratio of that proportionality increases directly as the volume increases.

It is known from the fundamental principles of thermodynamics that during an infinitesimal change of state of a perfect gas the increment of heat supplied is $dh = kdt + pdv$, in which k designates the specific heat of the gas at constant volume; and by definition the corresponding increment of entropy is :

$$de = \frac{dh}{t} = k\frac{dt}{t} + \frac{p}{t}dv;$$

therefore, by equation (1),

$$de = k\frac{dt}{t} + c\frac{dv}{v};$$

therefore

$$E = \frac{e - e_o}{c} = \frac{k}{c}\log\frac{t}{t_o} + \log\frac{v}{v_o}, \quad . \quad . \quad . \quad . \quad . \quad (4)$$

in which E is a quantity proportional to difference of entropy between any initial state $v_o t_o$ and any other state vt of the cycle, $k/c = 2.45$ for perfect gases, and *log* designates Napierian logarithm. In order to obtain values of E by construction, it will evidently be necessary to be able to find values of *log* from a table or curve. Such a curve can be readily constructed, as has been done in Fig. 2, to wit.: draw some sloping line OS through O, and taking any convenient point V_o, let $OV_o = v_o$, and with radius v_o cut the sloping line at S_o. From S_o drop a perpendicular to V_1, and let $OV_1 = v_1$. Again, use v_1 as radius and cut the sloping line at S_1. By continuing the process any desired number of points, $V_o, V_1, V_2, \ldots V_n$, may be obtained upon the horizontal line OV. Now note the points $U_o, U_1, U_2, \ldots U_n$, where the successive verticals, before mentioned, intersect respectively successive equidistant horizontal rulings. The points $U_o, U_1, U_2 \ldots U_n$ lie upon the desired logarithmic curve.

For, let $mv = v_1$, $mv_1 = v_2$, etc., and $mv_{n-1} = v_n$,
then $m^2 v_o = v_2$, $m^3 v_o = v_3$, etc., and $m^n v_o = v_n$.

Now let $m = e^{Dy}$, in which $e = 2.7 +$, the Napierian base, and $Dy = V_1 U_1$, the common distance between the equidistant horizontal rulings parallel to OV_o; then

$$e^{Dy} = v_1/v_o, \qquad e^{2Dy} = v_2/v_o, \text{ etc.},$$

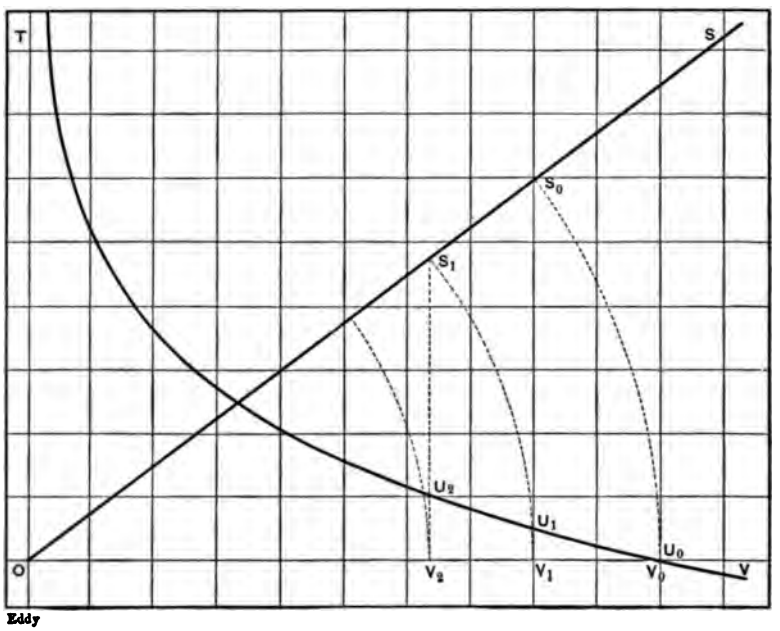
and

$$e^{nDy} = v_n/v_o; \text{ therefore } y_n = nDy = \log v_n/v_o \quad . \quad . \quad (5)$$

Hence the ordinate at any point V_n is $\log v_n/v_o$, in which v_o, the unit of comparison, is arbitrarily chosen. A polygon drawn through points determined by rulings so near together as those in Fig. 59 will differ by negligible amounts from the true curve.

The logarithmic curve or polygon constructed in Fig. 59 has been transferred to Fig. 60. It has been constructed separately in Fig. 59 simply for the sake of distinctness. It is asymptotic to OT. It may be noticed that the polygon which has

thus been constructed consists of successive diagonals of a set of parallelograms formed by equidistant horizontal rulings and vertical rulings which are nearer together the nearer they lie to the asymptote OT; hence we may begin with v_1 or either other value of v as the unit of comparison, and by drawing successive diagonals obtain the same polygon displaced through some distance vertically. In other words, it is of no consequence what horizontal be regarded as the zero line from which to reckon $\log v/v_o$. So far as the computation of E is concerned, the addi-



Eddy

FIG. 59.

tion to or subtraction of a constant from each of the values of $\log v/v_o$ will have no effect except to move the *et* diagram to the right or left, by increasing or decreasing all values of E by the same amount, a matter of no importance in a closed curve such as the *et* diagram, as will be seen when the objects sought by its use come to be seen. The situation of the *log* curve with reference to the asymptote is the important matter.

In order to construct the last term in the second member of equation (4), we need a table or curve from which to obtain values of $2.45 \log t/t_o$. Such a curve will now be drawn.

It is evident, since all curves of logarithms are alike in shape

and are related in the same manner to their asymptotes, that if a copy of the curve or polygon already constructed be placed with reference to OV as asymptote precisely as the curve for log v/v_o is placed with reference to its asymptote OT, then the distances of this curve from any convenient vertical will be the numerical values of log t/t_o. Furthermore, the question as to which vertical shall be taken to count from as zero will be determined by what choice is made as to t_o, the unit of comparison, for t_o will be the ordinate of the curve log t/t_o on the vertical

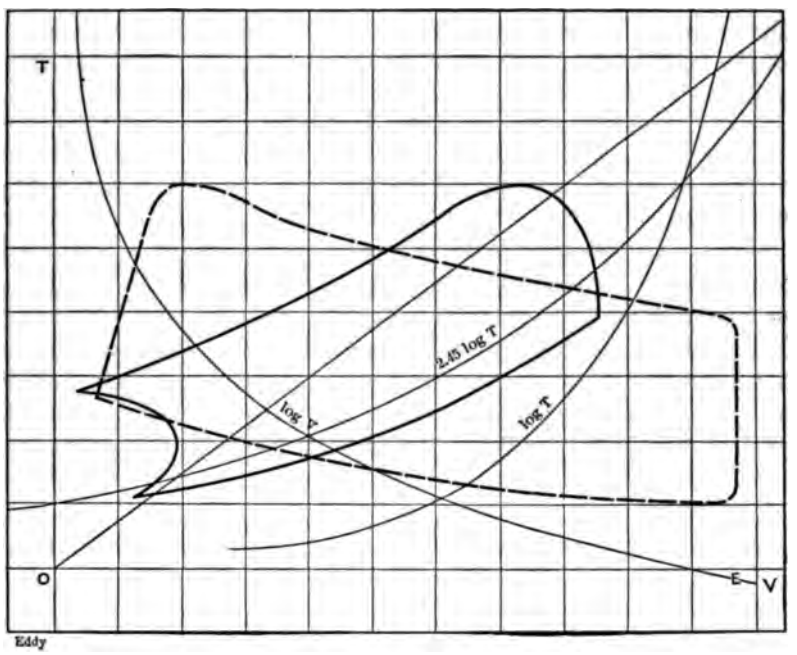


FIG. 60.

from which we count values of the *log*. The scale of temperatures which has been used is arbitrary, and hence it is of no consequence which vertical be regarded as zero. It will be convenient to write $T = t/t_o$, and $V = v/v_o$.

In Fig. 60, besides the logarithmic curve having OT for asymptote, another has been drawn with OV for asymptote.

This second curve, which may be called for brevity log T, has its points situated on a set of equidistant vertical rulings at the same distances from OV as the points of the first curve (log V, say) are situated on a set of equidistant horizontal

rulings from OT, in case the two sets of rulings form squares. But in order to construct the last term of equation (4) and so obtain 2.45 log T, it is sufficient to make a curve with the same vertical ordinates as log T, and with its horizontal distances 2.45 times as great as log T. In other words, if a set of vertical rulings 2.45 times as far apart be used, and the same set of distances from OV, the curve or polygon will give values of 2.45 log T measured from any convenient vertical. Such a curve is shown upon Fig. 60.

Now in employing these curves in order to find a point et of the entropy temperature diagram corresponding to any point vt of the volume temperature diagram it appears, since by equation (4)

$$E = 2.45 \log T + \log V,$$

that it is only necessary to correct the position of the corresponding point of the curve 2.45 log T by the value of log V as follows: At the temperature level t of any point vt note first where that horizontal cuts the curve 2.45 log T, and note, secondly, where the vertical v for this point vt cuts the curve log V; then the positive ordinate of the curve log V above the assumed zero of that curve is to be measured off to the left of the curve 2.45 log T, while any negative ordinate of log V (below zero) is measured to the right of 2.45 log T.

The locus so constructed is the et diagram, in which the scale of temperature is arbitrary, as has been shown, but the scale for difference of entropy is such that it is expressed in units of c, for by equation (4) we have, in case c is taken as unity,

$$E = e - e_o.$$

The heavy line in Fig. 60 is the et diagram thus determined, in which the corresponding points of the vt diagram are found on the same horizontal line of temperature, and the right-hand sides of the two diagrams correspond to each other, as also the left-hand sides.

It will be seen then that the concave sickle-shaped side (down at the left of the et diagram) corresponds to the compression side of the vp card. Since the temperature rises during the first part of the compression more rapidly than in adiabatic compression, by reason of the initially hot cylinder, the curve at first slopes upward to the right, until it reaches a tempera-

ture where, on the whole, no heat is received or lost by the air, where the curve is vertical, as it must be during any adiabatic change. From that point the curve slopes more and more to the left until it becomes nearly horizontal at the end of the compression, where the temperature almost ceases to rise. The upper side of the *et* diagram corresponds to the expansion side of the *pv* card: the first part of it, during the great rise of temperature due to injection of combustible, slopes upward to the right, but less and less rapidly until the maximum is reached, and then a gradual fall of temperature ensues, which becomes more and more rapid to the point of release, where it is nearly vertical, showing adiabatic expansion. From this it is clear that at release the gas is still, on the whole, receiving heat from continued combustion as rapidly as it is losing it by contact with the walls of the cylinder. The temperature at release is so high that it seems probable that combustion is not complete at that point, but is completed during exhaust. The lower side of the *et* diagram corresponds to the nearly vertical sides of the *vp* and *vt* cards during the exhaust, during which p and t fall, but v is supposed to remain nearly constant. This lower side, consequently, is a piece of the curve 2.45 log T moved to the right or left a suitable distance. The peculiarities of the *et* diagram thus afford important information as to the nature of this cycle, in addition to the determination of its efficiency. The efficiency, as is well known, is to be found by obtaining the ratio of the area of the *et* diagram to the rectangle whose lower side lies in $O\,V$, and whose other sides touch the *et* diagram. In Fig. 60 that ratio is somewhat more than one-third, as may be found by planimeter or otherwise. The points of the *et* diagram which need to be determined most carefully are the extreme right and left points, especially the latter, for a slight inaccuracy may easily occur, and indeed is somewhat difficult to avoid; but such inaccuracy has a considerable effect upon the efficiency.

In Fig. 61 the *et* diagram of an Otto cycle gas engine is constructed from an indicator card given by Dugald Clerk.* In it we have put all the steps of the construction on one sheet, as should be done in practice. A comparison of this *et* diagram with the former one shows the great advantage of high com-

* "The Gas and Oil Engine," 6th ed., page 316. See also pp. 377 and 383.

pression in giving a sufficient sweep to the sickle-shaped curve on the left to give depth to the *et* diagram and make the efficiency high. In the *et* diagram of the Otto cycle, the part between maximum temperature and release slopes downward to the left in a way that shows how rapidly heat is escaping through the cylinder walls to the great loss of efficiency. It was mentioned earlier in this paper that a *pt* (pressure temperature) diagram could have been constructed in a manner like that in which the *vt* diagram has been obtained. Had that been done, the steps

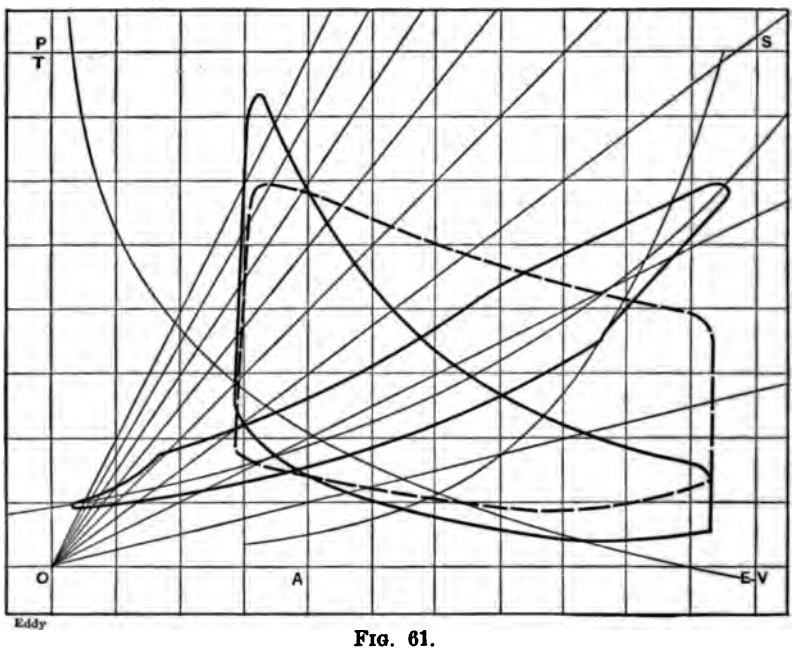


FIG. 61.

necessary to then obtain the *et* diagram would have depended upon the equations:

$$dh = k^1 dt - v dp;$$

therefore

$$de = k^1 \frac{dt}{t} - c\frac{dp}{p};$$

therefore

$$E = \frac{e - e_o}{c} = \frac{k^1}{c} \log \frac{t}{t_o} - \log \frac{p}{p_o} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

in which $k^1 = k + c$ is the specific heat of the perfect gas at constant pressure and $k^1/c = 3.45$. The graphical construction

for equation (6) could be carried out in a manner analogous to that already given for equation (4). Equation (6) may then be written in the simpler form :

$$E = 3.45 \log T - \log P.$$

DISCUSSION.

Mr. Arthur J. Frith.—The paper of Mr. Eddy is of great interest to us all who are engaged in the practical discussion of thermodynamic problems; his methods of determining volume temperature and entropy diagrams are clever and practical, and should call for commendation, and I have no wish to be critical in regard to the method explained to us. I regret, however, that I must take exception to its application to the card of the Diesel Oil Engine, in which I believe he has fallen unintentionally into a serious error, which I shall endeavor to point out briefly. In applying thermodynamic formulæ, one should always be careful that the conditions understood as underlying them are present in the example treated. Thus if air be compressed in a cylinder without loss of heat, we would obtain upon a card an adiabatic line to which the well-known formulæ can be applied; but if the cylinder were provided with a valve through which air either leaked outward to the atmosphere or inward from a reservoir of higher pressure, it is evident that we would obtain lines on our card to which the formulæ or their deductions could not in reason be applied. In short, the weight of air has changed during the compression, and our formulæ are understood to apply to changes in a perfect gas of a constant weight.

It is precisely this error that has crept into the discussion of the card of the Diesel Oil Engine, in which the weight of gases is not constant throughout the cycle; for, in the downward stroke of the piston fresh air is drawn in, on the second stroke it is compressed, but on the third stroke the fuel is injected into the cylinder with a blast of air that adds about 10 per cent. to the weight of the cylinder contents and is present during the exhaust.

So that the weight of gases to which the upper line of the card refers is about 10 per cent. greater than that to which the lower line belongs. I believe the paper is in error on pages 276

and 277, and in the check mentioned, when referred to this particular card. The temperatures mentioned on page 278 are also in error for the same reason, due to the peculiarity of the cycle, and not to the method employed. I present the same card (Fig. 62.) in which the lower line is divided into tenths, etc., to

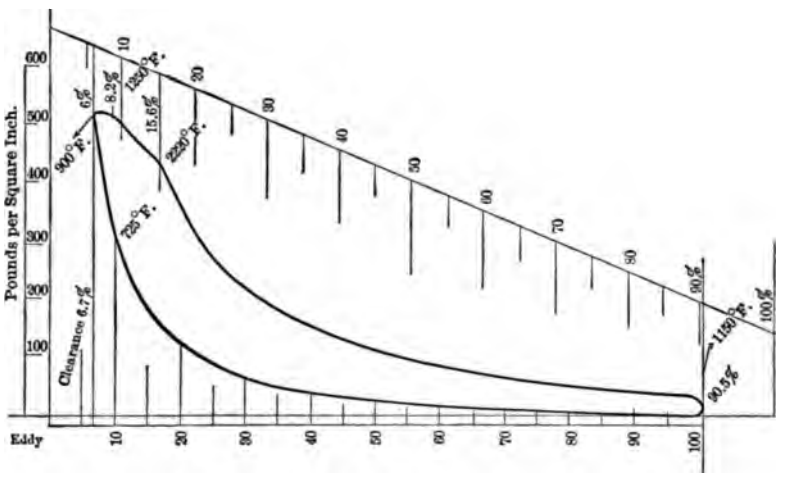


FIG. 62.

correspond to percentage of volume, and in which the divisions of the upper line are in percentages of a card line 10 per cent. longer than the lower; by which we obtain a compression temperature of 915 degrees Fahr., a maximum temperature of 2,220 degrees, and a release of 1,150 degrees Fahr. It may interest the Society to describe the graphical method of obtaining these temperatures. I have used a sheet of cross-section paper, a horizontal line of which represents the volume in percentages of the stroke, and the vertical scale the pressures taken in atmospheres. Upon this has been plotted a series of isothermal lines corresponding to equal changes of temperature: 32 degrees, 100 degrees, 300 degrees, 500 degrees, etc., up to 3,400 degrees. On the same sheet are plotted the adiabatic lines for compression from the same various temperatures at volume of 100 per cent. With the aid of this chart one is able to discuss the thermodynamic relation of a large number of problems. Thus if the length of our card plus the clearance be divided into tenths and the volume and pressures of any part be taken from it, then the isothermal line that passes through a point of similar pressure

and volume in the chart gives the temperature of the gases at that point of the card, provided it was compressed from the temperature chosen in the construction of the chart. If a different temperature exists in the starting point of the card, the result from the chart is modified by the ratio of the absolute temperatures according to the well-known formulæ. By this chart the theoretical expansion line can be laid out on the card, and the variation of temperatures and pressures noted, or it may be used to obtain the temperature volume and entropy diagrams to which this paper refers.

*Mr. Henry T. Eddy.**—It gives me pleasure to state that my views agree perfectly with those so well expressed by Mr. Frith as to the importance of having the mathematical assumptions made in the treatment of any problem agree as exactly as possible with the actual conditions of that problem. It is, nevertheless, a fact that in the treatment of every engineering problem some simplifying assumptions are necessarily made, which are usually of a character such that the error involved may be safely neglected or otherwise allowed for.

In casting about to discover authentic cards with which to illustrate the method I wished to propose in my paper, I found difficulty in obtaining those suitable for my purpose. Most published cards are inadequate, either by reason of their small scale or some imperfection of detail. I was therefore glad to avail myself of Professor Denton's card of the Diesel oil engine, reproduced in Fig. 58. I regret, however, to state that, having had no opportunity for practical experience with the Diesel engine and having access to no more extended description of its operation than that contained in the report of Professor Denton, referred to previously, it had escaped my attention that the air pump and receiver which operate as a starting device in this engine, as also in many other gas and oil engines where the starting device has no function other than to put the engine in motion, also operate continuously in this engine to introduce the oil, stroke by stroke, as part of the regular action of the engine. This oversight, while it furnishes no objection whatever against the general method I have proposed, does, as Mr. Frith says, impair the accuracy of the application of the method to the case of the Diesel engine, because the card given by Pro-

* Author's closure, under the Rules.

fessor Denton does not refer throughout to one and the same body of air. Very curiously, however, this construction, which is evidently too rough an approximation to be admissible, does actually in this case give the same numerical value for the efficiency as that computed by Professor Denton—viz., 36 per cent. But that result does not assure us that any such gratifying coincidence would usually occur. We must in some way construct a card which shall represent the cycle of the working air in the engine, and the question at once arises whether the method proposed by Mr. Frith does this. On examination it will, I think, be found that it suffers from an error of the same kind as that we have just considered—viz., it treats a hypothetical case too remote from the actual case to be admissible. For the air which expands in the working cylinder has been derived from two sources, and its two parts have undergone compression under very different circumstances. The larger part has been compressed by the working cylinder, and its curve of compression is that of the working cylinder in Fig. 58. The assumption of Mr. Frith really is, that the other and smaller part of the air with which the working cylinder becomes charged has the same compression curve also. This is far from being the fact, for the walls of the air cylinder are much cooler during its compression stroke than are those of the working cylinder, which latter have become greatly heated during the combustion of the fuel. Not only are the walls of the air cylinder at a far lower average temperature during compression, but they have a much larger area in proportion to the amount of the air enclosed, and so exert a greater proportionate cooling effect.

In the 20-horse-power Diesel engine tested by Professor Denton the air cylinder had a cubic capacity approximately $\frac{1}{18}$ as great as that of the working cylinder and an interior surface less than $\frac{1}{4}$ as great. It, however, makes two compression strokes to every one of the working cylinder. Hence, in case equal differences of temperature existed between the contents of each of the two cylinders and their respective cylinder walls, the wall of the air cylinder would exert more than three times as much effect as the other in keeping the temperature of its contents in equality with the metal enclosing its charge. Just what the compression curve for the air cylinder may be can be learned only from an indicator card taken from that cylinder, which must necessarily be taken in any admissible graphical

treatment of the cycle of this engine. That it differs greatly from that of the working cylinder is evident, because of its far lower temperatures and consequent smaller volumes per pound of air at equal pressures in the two cylinders. In case we have the compression curves of the two cylinders, the next question which arises is as to the manner in which they shall be combined in order to obtain a correct total compression curve for the contents of the two cylinders together.

Lay off as base lines for the cards of the two cylinders horizontal distances whose lengths represent to some convenient scale the volumes of the two cylinders (not their piston displacements). Then the sum of the volumes shown by the cards for each pressure is the volume of the entire amount of air in both cylinders at that pressure. This comes to the same thing as drawing a new compression curve at the right of the one shown in Fig. 58, starting on the atmospheric line at a point to the right of the lower right-hand extremity of the present compression curve at a horizontal distance equal to the volume of the air cylinder on the same scale of volumes as is employed for the working cylinder; *i.e.*, about $\frac{1}{3}$ of the piston displacement of the latter. This new compression curve should then be completed by making it lie at each pressure at a horizontal distance to the right of the present compression curve equal to the volume shown on the indicator card of the air cylinder for that pressure. While at atmospheric pressure the volume of air in the air cylinder is about $\frac{1}{3}$ of that in working cylinder, at high pressures it is much less, owing to far lower temperatures. The total work of compression in the two cylinders will be that under the compression curve so constructed. The total work of expansion is given by the present expansion curve, which should not be altered. In this construction it is considered admissible to neglect the work of compression of the total body of air until its total volume is equal to that of the working cylinder, and also the work of compression of the air cylinder above the highest pressure in the working cylinder. This is partially balanced by kinetic energy of the entering charge, etc.

It will be noticed that in this we propose to correct the original card by changing the compression curve in accordance with the actual variation of volumes, and not, as proposed by Mr. Frith, by the change in weight of the contents of the cylinder, which is a fundamentally erroneous conception.

Having treated the corrected indicator card of the cycle, the next question is that of temperatures. Let a meter with suitable equalizing chamber be attached to the intake of the working cylinder, and another to that of the air cylinder. Then, knowing the volume, pressure, and temperature of the air supplied in a given number of strokes, and combining it with the piston displacement for the same strokes and pressure at the end of admission, the temperature of the air at the end of admission may be found by equation (1) for each cylinder.

It will be sufficiently correct to assume that the exhaust gases in the clearance of the working cylinder remain at the temperature of exhaust—*i.e.*, at more than 1,000 degrees Fahr.—until the end of admission without mixing with the air admitted. For, as will be shown, the volumes and pressures are unchanged by mixing. Having thus found the absolute temperatures at the beginning of the compression in each cylinder, it will be perfectly possible to follow the march of temperatures in a volume-temperature diagram for each compression curve by the method proposed in my paper, and from the temperatures so obtained divine the temperature of the contents of both cylinders mixed at any pressure. For, let n_1/n_2 be the ratio of the quantities of air supplied to the two cylinders as shown by the meters, in which the subscripts refer to the two cylinders. This is also the ratio of the weights of the air supplied. For convenience, let $n_1 + n_2 = 1$. Then, since the specific heat of air is constant, $n_1t_1 + n_2t_2 = t$ is the temperature of the mixture, and we have $n_1v_1 + n_2v_2 = v$, in which v is the total volume of 1 pound of air when n_1 is the fraction of 1 pound in the first cylinder and n_2 in the second at the common pressure p. But v is also the volume in case the two fractions of the pound are mixed and occupy the same total volume as before.

For, by equation (1),

$$\frac{v}{t} = \frac{v_1}{t_1} = \frac{v_2}{t_2} = \frac{c}{p};$$

therefore, by composition of proportions,

$$\frac{v}{t} = \frac{n_1v_1 + n_2v_2}{n_1t_1 + n_2t_2} = \frac{c}{p}.$$

But since $t = n_1t_1 + n_2t_2$ is the temperature when the air of the cylinders is mixed at pressure p, $v = n_1v_1 + n_2v_2$ is their

volume mixed also. There is somewhat greater difficulty in finding the temperature at the beginning of the expansion, because the air cylinder compresses its charge to a considerably higher pressure than the working cylinder, and this air also has opportunity after compression to lose its heat in passing through the receiver before it enters the working cylinder. It would seem best to observe its temperature by a thermometer just before admission to the working cylinder, and then, assuming adiabatic expansion during admission, determine the temperature of its admission to the working cylinder. The temperature so found will then be used in the above formula for finding the temperature of the mixture.

There are certain questions arising in this part of the diagram due to the greater compression of the air cylinder and to the fact that this charge is admitted during so large a fraction of the stroke as is the case, the discussion of which will not be undertaken here. In brief, they can be settled by the application of the equation last given, an equation which admits of convenient graphical treatment. It will be admissible to assume that the total charge is introduced at the point where the expansion curve intersects the corrected compression curve, which point then becomes the end of the compression curve and beginning of the expansion for the total body of air.

The object of the paper, however, as shown by its title, is to establish a general graphical method of construction and give some idea of its capabilities rather than to apply it to any particular case. That object has, I think, been accomplished; but it would, I fear, have been much obscured had it been encumbered with the details necessary to the full discussion of a practical case.

No. 837.*

FRICTION OF STEAM PACKINGS.

BY CHAS. HENRY BENJAMIN, CLEVELAND, OHIO.
(Member of the Society.)

IT is generally conceded that one of the most serious frictional losses in engines and pumps is that due to the rubbing of piston and valve rods in their stuffing-boxes, and that this loss varies with the kind of packing employed, the steam pressure, and the judgment of the engineer.

The writer is not aware, however, that any experiments have been described which would show the extent of this loss and the law of its variation. The experiments described in this paper were made at the laboratories of the Case School by senior students, under the direction of the writer. The apparatus used was constructed by Mr. E. O. Lieghley of the class of '98, and a few experiments made by him.

During the past year, Mr. G. S. Beckwith, of the class of '99, made a large number of tests with different varieties of packing, and the results seemed of such interest as to justify their presentation to this Society.

The general character of the apparatus is shown in Fig. 63. It consists of a cast-iron cylinder, 6 × 13 inches inside, fitted at each end with a cover and stuffing-box suitable for a two-inch rod. The proportions of the gland, etc., were taken from those of a well-known engine. The rod was given a reciprocating motion by means of a slotted crosshead and crank; a pulley on the crank was connected by a belt with the pulley of a transmitting dynamometer; steam was admitted to the cylinder by the vertical pipe shown in the figure, and the water of condensation was drained off from time to time at the bottom.

A steam gauge attached to the cylinder showed the internal pressure at each instant. The adjusting nuts of the glands were usually tightened only by the fingers, but when a wrench was

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

used, it was turned by a spring balance and the turning moment noted.

The travel of the rod was 4.25 inches, and the usual speed about 200 revolutions per minute, giving a piston speed of about

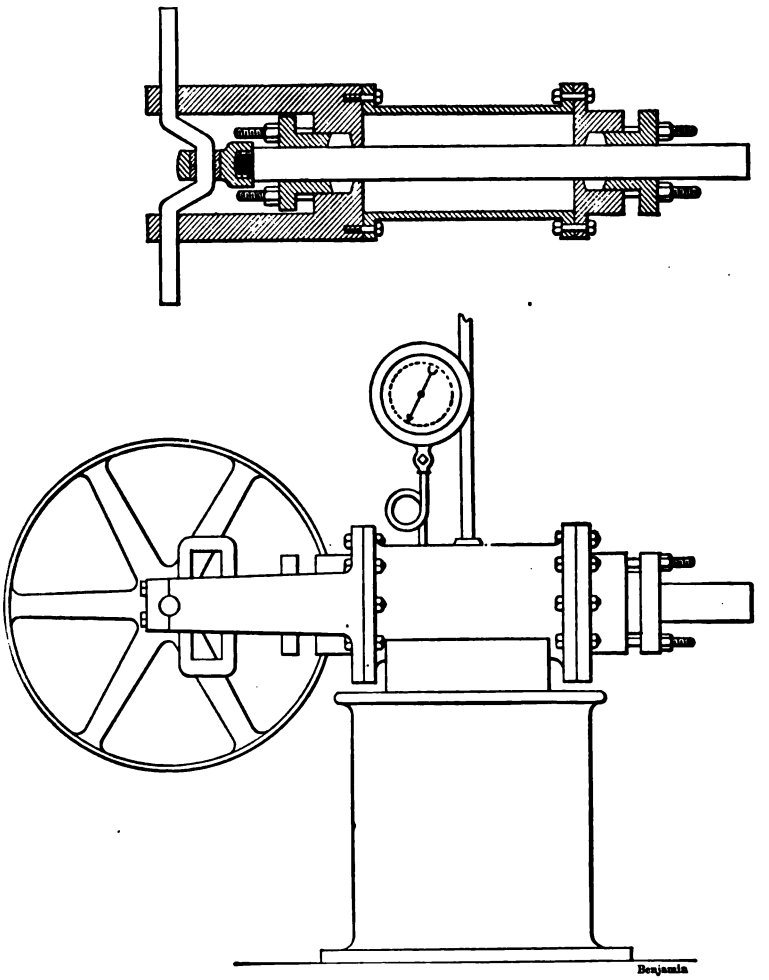


FIG. 63.

140 feet per minute. Seventeen different varieties of packing were tested, made by nine different manufacturers. The materials present were rubber, asbestos, cotton, flax or hemp, lead, mica, graphite, and paraffin. No metallic packings, strictly so called, were tried.

The following brief description will show the general characteristics of each variety:

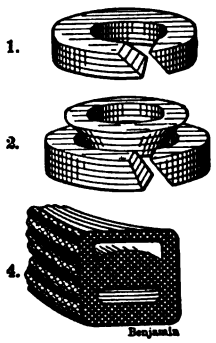


FIG. 64.

1 (Fig. 64). Square, ring, seven-eighths inch. Layers of canvas and rubber, saturated with graphite and oil.

2 (Fig. 64). Sectional, ring, seven-eighths inch. Composition similar to No. 1. Each ring consists of an inner and outer cone, fitting together, and so wedging under pressure as to fit tightly to rod and box.

3. Similar in shape and composition to No. 1.

4 (Fig. 64). Metal face packing. Alternate soft and metallic rings. The metallic rings contain lead band, backed by rubber and flax, the whole wound with cotton braid.

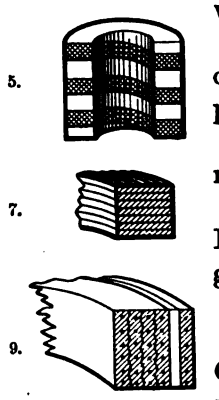


FIG. 65.

5 (Fig. 65). Two kinds: (*a*) a sleeve composed of woven flax, rubber, and canvas; (*b*) a spiral packing of woven flax backed with rubber.

6. Spiral, square, seven-eighths inch. Alternate layers of rubber and canvas.

7 (Fig. 65). Spiral, square, one-half inch. Layers of canvas and rubber, saturated with graphite and oil.

8. Similar to No. 7, but of a different make.

9 (Fig. 65). Spiral, square, one-half inch. Composed of rubber and asbestos compound, with elastic rubber inset. Slightly impregnated with graphite.

10. Spiral, circular, seven-eighths inch. Red rubber core, wound with layers of rubber and flax, and coated with graphite.

11 (Fig. 65). Spiral, round, half-inch. Two wedge-shaped strands of woven flax in centre, and two strands of canvas, the whole surrounded by a woven cover saturated with graphite and oil. There seemed to be also some paraffin present.

12. Spiral, round, half-inch. A rubber core, around which are braided three thicknesses of hemp or flax, soaked in oil. The whole coated with paraffin.

13. Spiral, round, one-half inch. A rubber core, surrounded with layers of woven cloth and rubber, impregnated with ground mica.

14. Square, one-half inch, pump packing. Alternate layers of canvas and rubber. No lubricant.

15 (Fig. 65). Square, one-half inch. Similar to preceding, but having a rubber back about one-eighth inch thick.

16. Square, one-half inch. Alternate layers of rubber and canvas. No lubricant.

17. Spiral, square, one-half inch. Woven flax, soaked in oil.

As at first constructed, the gland was adapted for packing seven-eighths inch thick. The flat ring and sectional packings of this size, such as Nos. 1, 2, and 3, worked well, but it was found that no spiral packing seven-eighths inch thick would coil easily around a two-inch rod. Accordingly, the box was bushed and a new gland made to accommodate one-half inch packing.

In cutting and inserting each kind of packing, careful attention was paid to the accompanying directions, and an endeavor was made to insure the most favorable conditions. It was not practicable to make endurance tests, but each packing was allowed to remain in the box long enough to get into fair working order.

The routine of each trial was about as follows: The apparatus was first tested empty of packing to determine friction.

The packing was then inserted and adjusted in each end, according to directions, and the steam turned on. The very least pressure which would prevent leakage was used on the gland nuts. The packing was then tested under various steam pressures, each run lasting from fifteen to forty minutes. The nuts were then tightened to various pressures, and other sets of readings taken. Cylinder oil was next applied to the rod, the only lubrication in the tests so far having been that contained in the packing itself. Finally, a last run was made with the boxes empty, as at first. A Flather recording dynamometer was used on a few of the runs, so as to determine the nature of the variations in power. The majority of the tests were made with a Webber box gear dynamometer, readings being taken at short intervals and averaged.

Table I. gives a summary of the results, showing the average horse-power consumed by each packing box at varying pressures and, for purposes of comparison, the power at 50 pounds pressure of steam. The friction of the machine has been deducted.

Table II. shows the effect of tightening the gland nuts on the friction of the packing and also the effect of oiling the rod.

In most of the experiments detailed in Table I. the nuts were tightened with the fingers only, and then just enough to prevent leakage, and no lubricant was used except that incorporated in the packing itself. With some of the dry rubber packings it was necessary to use oil from the first. A good quality of cylinder oil was applied.

The effect of varying the steam pressure is best shown graphically, as in Tables III. and IV. The numbers at the ends of the lines correspond to the numbers used in the other tables. The ordinates indicate the steam pressures observed, while the abscissas represent the horse-power consumed by each box. The points where these lines cut the line of 50 pounds pressure are those used for comparison of the different packings. It will be seen that the friction varies with the pressure in approximately straight line ratios in many of the cases.

General Conclusions.

1. That the softer rubber and graphite packings, which are self-adjusting and self-lubricating, as in Nos. 2, 3, 7, 8, and 11, consume less power than the harder varieties. No. 17, the old braided flax style, gave very good results.

2. That oiling the rod will reduce the friction with any packing.

3. That there is almost no limit to the loss caused by the injudicious use of the monkey-wrench.

4. That the power loss varies almost directly with the steam pressure in the harder varieties, while it is approximately constant with the softer kinds.

The diameter of rod used—two inches—would be appropriate for engines of from 50 to 100 horse-power. The piston speed was about 140 feet per minute in the experiments, and the horse-power varied from .036 to .400 at 50 pounds steam pressure, with a safe average for the softer class of packings of .07 horse-power.

At a piston speed of 600 feet per minute, the same friction would give a loss of from .154 to 1.71 with a working average of .30 horse-power, at a mean steam pressure of 50 pounds.

It is the intention of the writer to make a series of tests with

water packings, and also to try some of the standard forms of metallic packings. He would be glad of any criticisms and suggestions from builders and users of pumps and engines, in regard to any further experiments.

TABLE I.

Kind of Pack'g.	No. of Trials.	Total Time of Run in Minutes.	Average Horse-power Consumed by Each Box.	Horse-power Consumed at 50 Pounds Pressure.	Remarks on Leakage, etc.
1	5	22	.091	.085	Moderate leakage.
2	8	40	.049	.048	Easily adjusted; slight leakage.
3	5	25	.037	.036	Considerable leakage.
4	5	25	.159	.176	Leaked badly.
5	5	25	.095	.081	Oiling necessary; leaked badly.
6	5	25	.368	.400	Moderate leakage.
7	5	25	.067	.067	Easily adjusted and no leakage.
8	5	25	.082	.082	Very satisfactory; slight leakage.
9	3	15	.200	.182	Moderate leakage.
10	3	..	.275	....	Excessive leakage.
11	5	25	.157	.172	Moderate leakage.
12	5	25	.266	.330	" "
13	5	25	.163	.230	No leakage; oiling necessary.
14	5	25	.176	.276	Moderate l'kage; oiling necessary.
15	5	25	.233	.255	Difficult to adjust; no leakage.
16	5	25	.292	.210	Oiling necessary; no leakage.
17	5	25	.128	.084	No leakage.

TABLE II.

Kind of Packing.	Horse-power Consumed by Each Box, when Pressure was Applied to Gland Nuts by a Seven-inch Wrench.						Horse-power before and after Oiling Rod.	
	5 Pounds.	8 Pounds.	10 Pounds.	12 Pounds.	14 Pounds.	16 Pounds.	Dry.	Oiled.
1	.120	....	.136					
3	....	....	....	....	....	....	.055	.021
4	....	.248	....	.303	....	.390	.154	.123
5	....	.220						
6	....	.348	.430	....	....	....	.323	.194
7	....	.126	.228	.260	.330	.340	.067	.053
8	....	.363	.500	.535	.520	.533	.533	.236
9	....	.666	....	....	....	....	.666	.636
11	....	.405	.454	....	....	....	.454	.176
12	....	.161	.242	.359	.454	....	.454	.122
13	....	.317	.394	.582				
15	....	.526						
16	....	.327	.860					
17	....	.198	.277	.380				

TABLE III.
VARYING STEAM PRESSURE
SCALE 1 INCH = 0.1 H. P.

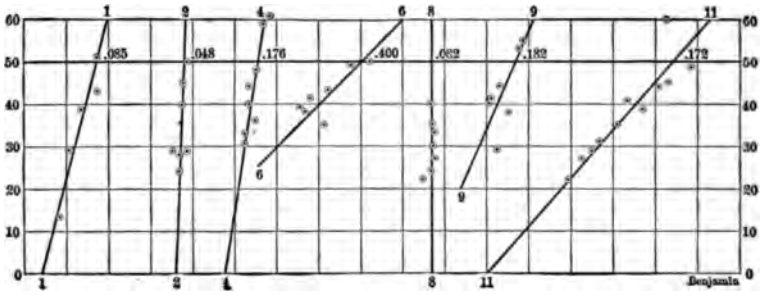
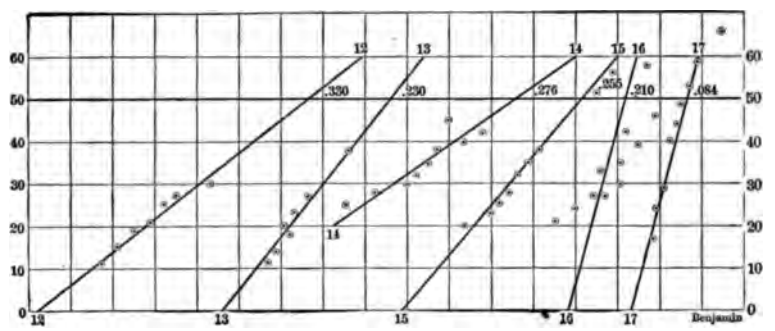


TABLE IV.
VARYING STEAM PRESSURE
SCALE 1 INCH = 0.1 H. P.



DISCUSSION.

Mr. Charles Longstreth.—I think that all mechanical engineers will agree with me that Professor Benjamin's paper touches upon a subject which is rapidly increasing in importance and is entitled to more consideration than it ordinarily receives. This is a question becoming of more importance to engineers, as steam pressures and piston speeds constantly increase, together with the number of piston rods and valve stems per engine.

A few years ago, when steam pressures of 50 to 80 pounds were used for marine work, there were only two important stuffing-boxes on a ship; while with the present steam pressures, some of them running as high as 250 pounds, the number of stuffing-boxes requiring packing is increasing to a hundred or more.

After reading the paper above referred to, one cannot but feel that it is disappointing, as the most important packings were not at all tested; also the method of testing is one which would not give reliable information to help the engineer select a proper packing.

The testing machine referred to in Professor Benjamin's paper has rod driven by a yoke. This rod is carefully guided by closely fitting glands at both ends of the cylinder (this cylinder does not contain a piston), and is driven and does not drive. Therefore the rod is not subject to anything like the vibratory movement which is caused by the ordinary steam engine, where the piston is used on a rod without any tail rod attached to the same, and with a crosshead running on guides. Also, the packings were not subjected to any sudden blows caused by the steam being admitted, as it is in the ordinary steam engine; and also were not subjected to the sudden compression with the return of the piston, all of which affects the packing both regarding friction and length of wear.

A packing which would work and show good results on the machine above referred to would most likely be almost worthless when applied to a large majority of steam engines on actual work. The packing which would probably have given the finest results on this testing machine is that which was invented by Professor Sweet and used on his well-known straight-line engines, and which, theoretically speaking, is probably the finest packing known, for the reason that it is not a packing, but merely a long sleeve, closely fitting the rod, with several water grooves, so that the only bearing upon the rod in this packing is water. I have had the pleasure of seeing this packing work beautifully. Of course, the friction caused is purely nominal, but this packing would be worthless if applied to the modern locomotive or marine engine, as it did not provide for any vibratory movement of the rod.

The master mechanics of one of the largest railroads of this country consider this vibratory motion of such importance that they will not consider a rod packing which does not at least allow them to run their engines with piston heads $\frac{1}{4}$ inch smaller in diameter than the cylinders, when crossheads are often run with $\frac{1}{16}$ inch play between them and the guides. This, of course, will cause considerable vibratory motion to the piston rod.

For marine work these conditions may not be so severe, but

still they exist in a more or less degree, and packing designed to meet these conditions—that is, the conditions which really exist with the actual running engine—will cause more friction than Professor Sweet's packing, but at the same time will give much better satisfaction, and prevent leakage of steam, and cause less friction than the comparatively solid packing referred to by Professor Benjamin, and be successful where Professor Sweet's packing might absolutely fail if applied to these severe conditions. Therefore, I think the method of testing referred to in the paper presented is of little value; but if asked how to test packing for friction, I frankly admit that I do not know of any means of testing, except by observing the performance of packings on an actual running engine under service conditions, noting the wear on rods and the expense of maintenance.

Thus when we see a triple-expansion engine which has been running five years with one kind of packing on a high-pressure rod, and another kind on the intermediate and low-pressure rods, and while the high-pressure rod has a shoulder of $\frac{1}{32}$ inch, and intermediate and low-pressure rods a shoulder of $\frac{1}{8}$ inch, we naturally think the first packing gives much less friction than the other.

I think Professor Benjamin's remarks about carelessness in the use of the monkey-wrench entirely apropos, and from my point of view the only way to make packing satisfactory is to take the adjustment of same entirely out of the hands of the mechanic running the engine. This has been quite successfully done with a number of prominent metallic packings now in use.

A Test of Metallic Packing.

In connection with the paper by Prof. Charles H. Benjamin, it may be interesting to note the results of a test by Prof. Sidney H. Reeves at the Worcester Polytechnic Institute. The test was between a well-known fibre packing and the Harthan metallic packing, and is as follows:

MR. FRANK E. HARTHAN, Superintendent,
Reeves Machine Company, Trenton, N. J.

Dear Sir—I beg to submit the following report of the tests made here of the comparative friction of soft ("XXXXX") packing, and your metallic packing in the stuffing-box of our 10 x 30 inch Allis engine. You may draw your own conclusions from the figures given; in general, I am glad to say we like your packing as to tightness and lack of trouble.

The friction was measured by the two methods: (1) By moving piston rod and crosshead by a cord attached to the latter and carried over a pulley made by a bicycle wheel on ball bearings to a variable weight; and (2) by the use of steam pressure measured by means of a mercury column. In the first case the cylinder was cold. In the second the conditions of actual operation were more nearly copied; the admission valves of the engine were out, so that the pressure on the two sides of the piston was known to be equal; but the unbalanced pressure on the area of the rod served to overcome the stuffing-box friction.

The same kind of oil was used in all tests. The first tests with the soft packing were made on the engine as it had stood for several weeks without use. After the soft packing had been tested, the rod was removed and turned down, the crank end proving to be 0.007 inch larger than the other.

The figures are in pounds, net. x refers to the friction of the piston; y, that of the stuffing-box; and z, that of the crosshead. Each figure given is the result or average of quite a large number of readings.

Results with Soft Packing.

Number.		
1	z..... 6.	
2	x, y, and z..84.	Cylinder hot, but practically unoiled.
3	x, y, and z..42.5.	Cylinder hot and oiled.
4	x and y.....84.	Cylinder hot and oiled.
5	x, y, and z..52.5.	Cylinder hot and oiled, packing tightened by two turns of the nuts.
6	x, y, and z..57.5.	Cylinders hot, but as left from two days before.
7	x, y, and z..40.5.	Cylinders hot and oiled.
8	x, y, and z..48.5.	Cylinders hot and oiled.
9	x, y, and z..53.5.	Cylinders hot, but after a day's rest.
10	x, y, and z..88.5.	Cylinders hot and oiled.
11	x, y, and z..49.	By steam method.
12	x, y, and z..49.5.	By weight method immediately afterwards.
13	x, y, and z..55.5.	Cylinder hot, but after a day's rest.
14	x, y, and z..43.5.	Cylinder hot and oiled.
15	x, y, and z..46.	Cylinder hot and oiled, and half-turn on nuts.
16	x, y, and z..56.5.	Cylinder hot and oiled, and one turn more on nuts, giving probable average working conditions.
17	x, y, and z..65.	Cylinders hot and oiled, and another half-turn on nuts.
18	x, y, and z..91.	Cylinders hot and oiled, and cylinders as tight as is occasionally used.
19	x, y, and z..20.	Cylinder hot and oiled; packing removed.

Results with Metallic Packing.

20	x, y, and z..40.5.	Cylinder hot, but unoiled.
21	x, y, and z..24.	Cylinder hot and oiled.
22	x and z.....20.5.	Next day cylinder cold.
23	x, y, and z..24.	By steam method.
24	x, y, and z..27.	Cylinder in same condition, but by other method.
25	x, y, and z..27.5.	Cylinder in same condition next day.
26	x, y, and z..22.	Cylinder hot and oiled.
27	x and z.....19.	Cylinder hot and oiled.

28	*x* and *z*.....20.5.	Cylinder cold, after four days' rest.
29	*x* and *z*.....18.	Cylinder cold and oiled.
30	*x*, *y*, and *z*..29.	Cylinder cold and oiled, but crosshead roughened by rotation on guides.
31	*x*, *y*, and *z*..18.5.	The same after crosshead has been scraped.
32	*x*, *y*, and *z*..17.	Next day cylinder cold and oiled.
33	*x* and *z*.....14.	Cylinder cold and oiled.

Yours truly,

(Signed) SIDNEY A. REEVE.

Excluding tests 1, 2, 4, and 19, which do not represent actual conditions, the average for fibre packing is 52.6. In a like manner excluding tests 20, 22, 27, 28, 29, and 33 gives 23.62.

The average of piston and crosshead tests, numbers 19, 22, 27, 28, 29, and 33, gives 18.66, and deducting this from the other results gives 33.94 for fibre, and 4.96, or a ratio of 1 to 6.84.

Taking tests 15, 16, 17, and 18 as representing actual conditions gives 64.62, or deducting 18.66 = 45.96, and this compared with the 4.96 obtained before leaves a ratio of 1 to 9.26.

Those who differ as to the conditions can, of course, choose any set of figures they wish in drawing conclusions as to ratio of friction between the two packings, but I have endeavored to be fair to both sides.

The effect of packing friction on valve stems on the governing of high-speed engines is well known, and if metallic packing will give such results as this, engineers are sure to be interested.

Mr. F. A. Halsey.—The remark made regarding Professor Sweet's piston-rod packing, to the effect that it is not adjustable to permit side motion of the rod, should be corrected, as it is conspicuously wrong. A ball-and-socket joint and a transverse sliding joint permit absolute freedom for perfect alignment in all directions.

Professor Lanza.—I would like to ask the author, in his average horse-power consumed, how wide the variation of the separate tests was of which those were the average. For instance, when .091 is the average horse-power, what is the largest and what is the smallest?

*Prof. C. H. Benjamin.**—Replying to Mr. Longstreth's criticisms, I would say that the principal object of the experiments was not to make a comparison of the endurance and practical

* Author's closure, under the Rules.

value of different forms of packing, but to determine approximately the power lost in friction with such packings as are in common use in stationary engine practice, and this, I think, I have done.

Mr. Longstreth may not recognize the packings from my description, but the list comprises some of the most popular brands of rubber and canvas packings in this part of the country.

Metallic packings were excluded, because I wished to make another series of tests on that kind alone.

I am not familiar with that class of engines which allows from $\frac{1}{16}$ to $\frac{1}{4}$ inches vibratory motion to the rod; stationary practice in this vicinity does not show any such condition, and of the many sizes and varieties which I have tested not one has shown any appreciable motion of this character.

I agree with Mr. Longstreth that the best method of testing the relative endurance of packings is by actual service, but this would give no clue to the amount of power consumed in driving the rod. I have thought it best to approximate as closely as possible to actual conditions without introducing the frictions of crosshead and piston, which would be variable and indeterminate.

If there is any way by which the conditions of practice can be more closely imitated without introducing indeterminable factors, I should be glad to know of it.

In answer to Professor Lanza's question, I would say that the variation from an average was considerable, even when the conditions were apparently just the same. The variation from a mean averaged 28 per cent. for all the samples tested.

For instance, in the case of No. 7, a very good soft packing, the horse-power varied from .059 to .074. No. 14, a hard, dry, pump packing, varied from .118 to .246 horse-power.

In experimenting with pump packings under water pressure, I find by using a recording dynamometer a great fluctuation in successive strokes.

No. 838.*

THE BERTHIER METHOD OF COAL CALORIMETRY.

BY C. V. KERR, CHICAGO, ILL.
(Member of the Society.)

THE recommendation of the Committee on the Revision of the Code of 1885 Relative to a Standard Method for conducting Steam-boiler Trials, in its Report at the Washington Meeting, May, 1899, is that the heating power of the coal used on a given boiler test should be determined by combustion in an atmosphere of oxygen gas, and that the most perfect apparatus thus far brought out is the Mahler Bomb Calorimeter. But the admission is also made that the apparatus is complicated and expensive, and that probably not many engineers will have the instrument as a part of their equipment for testing boilers.

I desire in this connection to present some of the claims to favorable attention of what has been called the "Berthier method of coal calorimetry," which uses oxide of lead (PbO) as the source of oxygen. It requires only accurate weighing of the sample of fuel and an easily controllable fire for heating a clay crucible to a low red heat. There are no corrections for radiation and no delicate measurements of temperature to be made. These are, apparently, the great sources of error in the use of oxygen gas. The theoretical corrections necessary in the Berthier method are readily made once for all; and as the errors due to manipulation are easily avoided, I am confident that the method as explained below is worthy of much more frequent use.

An eminent French mineralogist and member of the Academy of Sciences, Pierre Berthier, was born at Nemours, France, in 1772. In 1833 he published in eleven volumes his chief work, "A Treatise on Assays by the Dry Method." In Volume I. of this work he describes his method of finding the heating power

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

of fuels as follows: "Mix intimately 1 part by weight of the substance, in the finest state of division, with at least 20, but not more than 40, parts of litharge. Charcoal, coke or coal may be readily pulverized; but in the case of wood the sawdust produced by a fine saw or rasp must be employed. The mixture is put into a close-grained conical clay crucible, and covered with 20 or 30 times its weight of pure litharge. The crucible, which should not be more than half full, is covered and then heated gradually until the litharge is melted and evolution of gas has ceased. At first the mixture softens and froths. When the fusion is complete, the crucible should be heated more strongly for about ten minutes, so that the reduced lead may thoroughly subside and

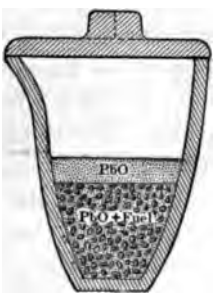


FIG. 67.

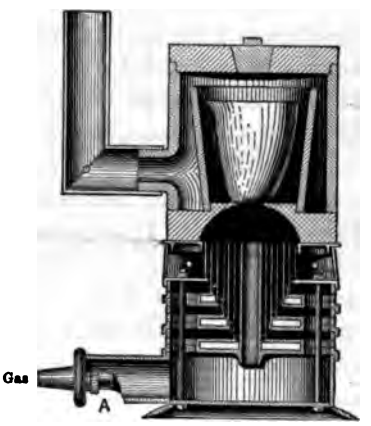


FIG. 68.

collect into one button at the bottom. Care must be taken to prevent the reduction of any of the litharge by the gases of the furnace. The crucible, while hot, should be taken out of the fire and left to cool; when cold, it is broken, and the button of lead detached, cleaned, and weighed. The accuracy of the result should be tested by repetition."

The litharge, or "stone silver," as the name signified to the alchemists, used in this process is an oxide of lead, PbO, formed by heating metallic lead in contact with air. If this oxidation takes place below the melting point of the oxide, the result is a dull yellow amorphous powder, called "massicot," which has the same composition, PbO. It melt sat a red heat, forming a dark-red transparent liquid. In the crystallized state following melting it has a buff color. The commercial litharge is often mixed

with red lead, Pb_3O_4, which is formed by heating massicot in air, or even with a small amount of finely divided metallic lead. Consequently, care must be taken to secure chemically pure litharge, intended for assayer's use. This has a dull lemon yellow or buff color.

In using litharge in clay crucibles a *bright* red heat should be avoided, because the liquid litharge combines with silica at a high temperature, forms a fusible silicate of lead, and soon perforates the crucible. This property occasions the use of litharge in the manufacture of glass and in glazing earthenware. The purpose of covering the mixture of fuel and litharge in the crucible with a quantity of pure litharge is not only to prevent access of air to the fuel, but also to prevent the escape, unoxidized, of the more volatile portions of the fuel. And this covering of pure litharge must likewise be protected from the furnace gases. A yellow flame like that of a gas jet would reduce the litharge to lead in the oxidation of the incandescent carbon of the flame, while the blue flame of a Bunsen burner would have no such effect. Some have not only covered the crucible, but luted it with clay to keep out the furnace gases. This is rather foolish than wise, since the gases, CO_2 and H_2O, formed in the crucible during the oxidation of fuel and reduction of lead must be allowed to escape or an explosion will ensue. The simple precaution necessary is to put on the crucible the usual clay cover to prevent particles of fuel falling in or an incandescent flame coming in contact with the litharge, which would cause the reduction of metallic lead.

Berthier based his method on what is known as Welter's law, which he expressed thus: "It has been proved by the experiments of many philosophers that the quantities of heat emitted by combustible substances are exactly proportioned to the amounts of oxygen required for their complete combustion." Thus a pound of carbon burning to carbonic acid gas, CO_2, unites with $2\frac{2}{3}$ times its weight of oxygen and evolves 14,600 heat units, or pounds of water raised one degree Fahrenheit:

$$C + O_2 = CO_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$12 + 32 = 44$$
$$\frac{O_2}{C} = \frac{32}{12} = 2\tfrac{2}{3}$$

And the heat evolved will be $14{,}600 \div 2\frac{2}{3} = 5{,}475$ heat units per

pound of oxygen used. If the oxygen is furnished by litharge, the chemical changes will be shown by the equation:

$$2PbO + C = CO_2 + 2Pb \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$
$$2(206.9 + 16) + 12 = 44 + 413.8$$
$$\frac{2Pb}{C} = \frac{413.8}{12} = 34.48$$

Now, by Welter's law, if the heat evolved is proportional to the oxygen used, it must also be proportional to the weight of lead reduced. For each unit weight of lead the heat evolved will be $14,600 \div 34.48 = 423.4$ heat units. Then the combustion of F pounds of fuel will evolve $423.4 \times \frac{L}{F}$ heat units per pound, in which L = weight of metallic lead reduced, and F = weight of fuel used.

But, unfortunately, Welter's law does not hold true for hydrogen compared with carbon.

$$2H_2 + O_2 = 2H_2O \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$
$$2 \times 2.02 + 32 = 2(2.02 + 16)$$
$$\frac{O_2}{2H_2} = \frac{32}{4.04} = 7.92$$

A pound of hydrogen evolves 62,000 heat units. Hence the heat per pound of oxygen used will be $62,000 \div 7.92 = 7,830$ heat units. This compared with the 5.475 in the case of the carbon shows too great a difference to be due merely to errors of observation. So that, in this simple form, the Berthier method must give incorrect results when used with fuels containing unknown mixtures of carbon and hydrogen. The method has, therefore, been generally discredited. The following, from Poole's "Calorific Power of Fuels," is a fair summary of the adverse criticism: "This formula was recommended by Berthier and has been used since by a few others. It is faulty, as was shown by some of Berthier's own determinations in which contradictory results were obtained. Dr. Ure showed that no uniform results could be obtained, using the same materials. Scheurer-Kestner in 1892 showed that the formula not only gave erroneous results, but actually reversed the relation of combustibles. . . . This method is allowable only in cases where the crudest approxima-

tions are desired, and where no analysis or calorimetric tests can possibly be made."

With the fundamental theory shattered, and such a load of adverse criticism to carry, it is apparently useless to investigate the Berthier method further. Nevertheless, it may be possible that a method of coal calorimetry correct in theory may on account of experimental errors give more widely varying or more erroneous results than one defective in theory, but freer from errors of experiment. That is the opportunity of the Berthier method.

When it is stated that the heating power of one pound of carbon is 14,600 British thermal units and of hydrogen 62,000, we are to understand that the combustibles are to be taken at 32 degrees Fahr. under atmospheric pressure, and that the products of combustion, carbonic acid gas and water, are to be returned to that temperature and pressure. If the hydrogen of a fuel is oxidized by reduction of litharge, the chemical changes will be represented by the equations :

$$PbO + H_2 = H_2O + Pb \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$
$$222.9 + 2.02 = 18.02 + 206.9$$

And the lead reduced per unit weight of hydrogen will be

$$\frac{Pb}{H_2} = \frac{206.9}{2.02} = 102.42$$

Then the ratio of lead reduced per unit weight of hydrogen to that per unit weight of carbon will be $102.42 \div 34.48 = 2.97$. Consequently, if Welter's law were true, the heating power of hydrogen would be $14,600 \times 2.97 = 43,362$ British thermal units, while it is actually greater than this by $62,000 - 43,362 = 18,638$ British thermal units. A fuel containing 2 per cent. by weight of hydrogen, as in the case of coke, charcoal, or anthracite, if judged by the formula

$$P = 423.4 \frac{L}{F}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

would be in error by $18,638 \times .02 = 373$ heat units. Then the constant, 423.4, must be increased by $373 \div 34.48 = 10.8$, making it to the nearest unit, 434, and the formula will be

$$P = 434 \frac{L}{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If the fuel contains an average of 5 per cent. hydrogen, as in the case of bituminous coal, lignite, and wood, the error will be $18,638 \times 0.05 = 932$ heat units; and the correction to the constant will be $932 \div 34.48 = 27$, making the formula

$$P = 450 \frac{L}{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The percentage of hydrogen in the fuels named is so nearly constant that the formulas (6) and (7) are probably within 1.5 per cent. of the correct value. If the proportion of hydrogen in a particular fuel is known, then the constant can be modified in the manner shown so as to give exact values. But the error in sampling alone is liable to be much more than 1.5 per cent.

Sulphur exists in almost every fuel in small but widely varying proportions, and it has a heating power of about 4,000 British thermal units per pound. It has not been considered as a combustible, however, for the reason that it occurs usually as iron pyrites, FeS_2, which must be dissociated before the sulphur can act as a combustible, the net result in heat units being doubtful.

When fuel is burned in the ordinary boiler furnace, a large excess of air is usually present, and the products of combustion are sent into the chimney at a high temperature. It may be of interest, therefore, to consider here the heat actually available in what is at present called good practice. Assume 18 pounds of air at 32 degrees Fahrenheit, and normal pressure, an excess of about 50 per cent., to be required for the combustion of each pound of fuel, and that the products of combustion together with the excess of oxygen and nitrogen to enter the chimney at a temperature of 400 degrees Fahrenheit. Then the loss of heat per pound of carbon burned will be about 1,600 heat units, the total carried away by the carbonic acid gas, the oxygen, and the nitrogen, while the hydrogen will lose almost 15,000 heat units, more than half of which is due to the latent heat carried away in the aqueous vapor or steam. The available heat then will be:

for carbon, $14,600 - 1,600 = 13,000$ British thermal units;
for hydrogen, $62,000 - 15,000 = 47,000$ British thermal units.

The excess of available heat in the hydrogen over that required

by Welter's law will be $47{,}000 - 13{,}000 \times 2.97 = 8{,}390$ British thermal units. The formulas will then be:

$$P = \frac{13{,}000}{34.48} \times \frac{L}{F} = 377\frac{L}{F}, \text{ for pure carbon} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$P = \left(377 + \frac{0.02 \times 8{,}390}{34.48}\right)\frac{L}{F} = 382\frac{L}{F}, \text{ for fuel with 2 per cent. hydrogen} \quad . \quad . \quad . \quad (9)$$

$$P = \left(377 + \frac{0.05 \times 8{,}390}{34.48}\right)\frac{L}{F} = 389\frac{L}{F}, \text{ for fuel with 5 per cent. hydrogen} \quad . \quad . \quad . \quad (10)$$

The advantage of formulas (9) and (10) is that they enable the evaporation of water per pound of fuel by a boiler plant in good condition to be directly determined. Thus, if a fuel gives a value of $L \div F = 30$, then $P = 389 \times 30 = 11{,}670$ British thermal units per pound of bituminous coal. If steam is formed at 100 pounds gauge from feed water at 202 degrees Fahrenheit, the heat put into each pound of steam will be 1,014 British thermal units. Hence the evaporation should be $11{,}670 \div 1{,}014 = 11.5$ pounds of steam per pound of dry coal.

The tables of calorimetric tests of various coals given herewith are intended to illustrate the degree of uniformity in results that may be expected with ordinary care and skill. Part of this work was done by students and part by the writer. The heating power of the bituminous coals was calculated some years ago from the formula $P = 430\ L \div F$. The determination of the heating power of charcoal derived from granulated sugar was made to show how much confidence would be supported by results of experiment on a fuel of known heating power. Favre and Silberman give 14,544 British thermal units for pure carbon; while Berthellot says 14,647 British thermal units. Both of these figures are averages of results of experiments by these skilled physicists on a fuel of constant heating power.

It was intended to compare the results by the Berthier with results by the oxygen calorimeter on a number of fuels. But the form of instrument available, even with the greatest care, gave such widely varying results that the comparison is not satisfactory.

In regard to the cost of material for calorimetric tests by the Berthier method, the clay crucibles will cost about 4 cents

each, and the charge of about 100 grams of litharge about 2½ cents. So that if five determinations are made for a given fuel, the total cost of material will be about 33 cents. A suitable furnace and a chemist's balance are supposed to be available. The manner of filling the clay crucible and the proper relative size of crucible and charge are indicated by Fig. 67. A 4-inch Denver clay crucible is large enough. It is well to use an excess of litharge, about 50 grams of PbO to one gram of coal, and to cover the mixture with about 25 grams of PbO. In Fig. 68 is shown a section of a satisfactory laboratory furnace for such purposes, with gas and air (*A*) connections indicated.

TABLE I.

BITUMINOUS COAL.

No.	Fuel.	Weight of Coal, Grams.	Time of Fusion.	Weight of Lead Button, Grams.	Calorific Power, B. T. U.	Average.
1	Huntington Fancy Lump..	1.8293	15 min...	55.9698	13,034	
2	" " " ..	2.0495	15 " ..	61.8461	12,855	12,935
3	" " " ..	2.0338	15 " ..	61.6578	12,915	
4	Pittsburg, Kan., Mine Run	1.182	8 " ..	29.994	10,823	
5	" " " "	1.0525	13 " ..	26.781	10,852	10,735
6	" " " "	1.318	12 " ..	33.166	10,732	
7	" " " "	1.414	13 " ..	34.914	10,531	
8	Ft. Smith, Ark., Mine Run	1.0019	13 " ..	28.4048	11,915	
9	" " " " "	1.4385	21 " ..	41.0555	11,995	11,969
10	" " " " "	1.2005	12 " ..	34.1865	11,970	
11	Baldwin, Ark., Lump.....	0.8819	12 " ..	23.626	11,260	
12	" " "	1.0594	13 " ..	28.5725	11,335	11,307
13	" " "	0.9950	22 " ..	26.8144	11,327	
14	Fayetteville, Ark., Lump..	1.2285	15 " ..	34.1030	11,870	
15	" " " ..	1.4895	15 " ..	40.6994	11,485	11,586
16	" " " ..	2.0625	15 " ..	57.3645	11,690	
17	" " " ..	1.6335	15 " ..	44.680	11,500	
18	Kansas Lump.....	1.127	15 " ..	29.4332	11,230	
19	" "	1.015	15 " ..	26.9328	11,150	
20	" "	1.019	15 " ..	27.1331	11,190	11,220
21	" "	1.0625	15 " ..	28.5901	11,310	
22	Huntington, Ark., Slack ..	1.9068	15 " ..	52.2333	11,143	
23	" " " ..	2.0335	15 " ..	53.5909	11,227	11,060
24	" " " ..	1.8686	15 " ..	47.4247	10,812	
25	Ind. Territory, Mine Run..	1.115	20 " ..	22.697	8,682	
26	" " " " ..	1.162	20 " ..	23.239	8,529	8,636
27	" " " " ..	1.382	20 " ..	28.158	8,696	

TABLE II.

COMPARISON OF OXYGEN AND LITHARGE METHODS.

No.	Fuel.	Weight of Fuel, Grams.		Heating Power.		Results.		Probable Error, Per Cent.	
		Oxy.	Lith.	Oxy.	Lith.	Oxy.	Lith.	Oxy.	Lith.
1	Carbon from Granulated Sugar. Ash, 0.44%.	.....	2.18	Calibration.	14,640	Calibration.	All.		
2		.....	1.882		14,800		14,330	9 Det.	6 Det.
3		.....	1.879		14,550		.....	.....	.....
4		.....	2.767		13,920		1,2,3.6	±2.6	±0.76
5		.....	2.919		13,590		14,617	.....	.....
6		.....	1.937		14,480		.....	.....	.....
7	Bituminous Slack from West Virginia.....	1.310	3.197	14,720	11,420	.....	.....	.....	.....
8		1.377	2.306	14,090	11,530	.....	.....	.....	.....
9		1.468	3.453	14,520	11,460	14,620	11,470	±1.1	±0.14
10		1.204	3.502	14,320	11,520	.....	.....	.....	.....
11		0.812	2.877	15,460	11,420	.....	.....	.....	.....
12	Anthracite Coal from Lehigh Valley.....	1.328	2.4535	12,660	13,560	.....	.....	.....	.....
13		1.372	2.3165	12,370	13,650	.....	.....	.....	.....
14		1.394	2.0000	12,520	13,604	12,760	13,616	±1.7	±0.08
15		1.538	2.0000	12,230	13,622	.....	.....	.....	.....
16		1.262	2.9675	14,000	13,643	.....	.....	.....	.....

DISCUSSION.

Prof. J. H. Kinealy.—The Berthier method of determining the heating power of coal is founded upon a so-called law announced by J. J. Welter about the end of the first quarter of the present century. This law as announced by Welter is:

The heat evolved by a combustion in which a unit of weight of oxygen is used is the same for all substances. It was based upon the results of the experiments made by Lavoisier and Laplace, Rumford and Crawford. The instruments used by these experimenters were, however, so crude that the results were not sufficiently accurate to warrant the general conclusion which Welter drew from them; and later and more accurate experiments have shown that the law is not true.

It is a mistake to speak of the method as a "method of coal calorimetry," or as a "method of determining the heating powers of coals." It is simply a method of determining the amount of oxygen required for the combustion of the oxidizable matter in the coal. Everything in the coal that is oxidizable acts upon the litharge, and results in setting free a certain amount of lead,

which goes to increase the size of the "button." There is absolutely no way of determining from the test how much of the lead of the button results from the oxidation of the carbon of the coal, or how much from the oxidation of either the hydrogen or the sulphur. And, in view of this fact, the author's statement, "The theoretical corrections necessary in the Berthier method are readily made once for all," is rather astonishing.

The method pointed out by the author, of making corrections for the presence of other oxidizable matter than carbon, presupposes a somewhat exact knowledge of the chemical composition of the coal, or at least a fair knowledge of the amount of combustible hydrogen in it; and this can be obtained only by a chemical analysis made upon a sample of the coal tested. It is true, however, that samples of coal taken from the same vein of a mine, or, in some cases, from the same district, will have about the same chemical composition. This being so, it follows that once having made a chemical analysis, an ultimate analysis to determine the amount of hydrogen in the coal, the heating power may be calculated, and thus determined once for all for coal from a certain mine or district. The heating power thus determined may afterwards be accepted for any sample taken from the mine or district without making a test by the Berthier method.

As a means of making an exact determination of the heating power of a coal, the Berthier method is absolutely worthless; and recommending it as a means for so doing is to be deprecated, because it deceives the layman and tends to retard the general use and adoption of a proper form of calorimeter. The method, however, has its value in aiding a buyer of coal to judge whether or not coal delivered to him from time to time during a season is of about the same quality as that agreed upon. The buyer judges by the appearance whether the coal delivered is as agreed it should be as to general size—*i.e.*, slack or pea or egg or lump, etc.; and also as to class—*i.e.*, bituminous, semi-bituminous, or anthracite; and by means of a test by the Berthier method determines whether or not the coal gives the lead button which it was agreed a sample of a given weight should give. The method can be used to great advantage in this way, because samples of coal of the same weight, taken from the same mine, or, in some cases, from the same district, will usually give buttons of very nearly the same weight.

In this connection it may not be out of place to call attention

to the fact that tests made with the Berthier method on the same sample of a coal will often give results which are more in accord with one another than the results of tests made with some of the forms of calorimeters used for making so-called exact determinations of the heating powers of coals. Table II., given in the paper, clearly shows that the oxygen calorimeter used by the author cannot by any stretching of the imagination be considered a very satisfactory instrument. It is too bad that he does not give the name of the instrument. I think that the statement, "It was intended to compare the results by the Berthier with the results by the oxygen calorimeter on a number of fuels. But the form of instrument available, even with the greatest care, gave such widely varying results that the comparison is not satisfactory," together with a single sentence giving the name of the calorimeter, would be of great and lasting value, as it would serve as a notice to others not to use or buy that calorimeter.

The results obtained by the Berthier method from the tests on carbon from granulated sugar only prove that the tests were carefully made and worked up. This is so, because the results were obtained by a calculation, to make which it was necessary to *assume as known* the heating power of carbon.

When 4 grams—about 62 grains—of coal are used with 160 grams of litharge, the ordinary Battersea H-crucible will be found to be of about the proper size to use. I think the suggestion of the author, to put about 10 grams of litharge on top of the mixture of coal and litharge a good one, although I have never seen it tried. A layer of common salt, about half an inch thick, on top of the charge of litharge and coal is better than a cover on the crucible.

I have never found it necessary to use chemically pure litharge. Ordinary commercial litharge, sold in small 25-pound kegs at 10 a cents pound, will give very good results.

The litharge and the crucibles may be tested to determine whether or not there is any oxidizable material in them, by heating in one of the crucibles the same weight of litharge that is used for one test. If a lead button is obtained, a new lot of litharge and new crucibles should be gotten.

*Prof. C. V. Kerr.**—I am indebted to Professor Kinealy for

* Author's closure, under the Rules.

facts concerning the history of Welter's law. The statement of that law, however, agrees in substance with that in the paper under discussion.

To say that it is a mistake to call the subject of the paper a method of coal calorimetry is to make the mistake of ignoring the fact that there may be both direct and indirect means of reaching a desired result. A coal calorimeter is merely an apparatus for determining the heat evolved in the combustion of a fuel; and as the thermometer gives one factor in the computation of heat by the oxygen methods, so the lead button gives one factor in the Berthier method. Nor do any of the methods, except chemical analysis, pay any attention as a process to the composition of the fuel. We are after heat.

If any one will take the trouble to read the published analyses of anthracite and bituminous coals of this country and Europe, he will probably be astonished, not that I have proposed one constant in the Berthier formula for bituminous coal and another for anthracite, but that the proportion by weight of hydrogen is so uniform in coal from widely separated localities and of widely different heating values.

From an ultimate analysis of a sample of coal from a given mine, the heating value may be estimated with more or less exactness *for that sample.* But the testimony of results as given, for instance, in Poole's "Calorific Power of Fuels," tends to show that heating values vary not only with the grade, whether lump, run of mine, or slack, but also with the authority even when that is of the highest. The truth seems to be that the errors of sampling and the influence of varying amounts of slate, dirt, and moisture in different samples of coal from a certain locality may occasion more variation in heating value calculated from ultimate analysis than will the variation in the proportion of hydrogen in samples from different localities. And as Professor Kinealy has been kind enough to admit "the fact that tests made with the Berthier method on the same sample of a coal will often give results which are more in accord with one another than the results of tests made with some of the forms of calorimeters used for making so-called exact determinations of the heating power of coals," it would seem as if his opinion that "as a means of making an exact determination of the heating power of a coal the Berthier method is absolutely worthless" must contain a strong admixture of hyperbole.

An ultimate analysis can not be depended on unless made by a skilled chemist with the best apparatus. In a somewhat less degree this statement applies to the results from the oxygen calorimeters on account of the possible errors of manipulation. Judged by the erroneous Welter's law, the Berthier method is admittedly faulty; but it is easy to use, and since the proportion of hydrogen in bituminous and anthracite coals is nearly constant, the formula for each may be fixed so closely that the error of the formula is probably within the errors of sampling a ton or car load, and therefore practically exact.

Engineers have been analyzing chimney gases for years to get an accurate idea as to the completeness of combustion of their fuel. Is it not a little strange that in the determination of heating values of fuels by the oxygen calorimeters the completeness of combustion seems to be taken for granted? In *Power* for December, 1899, Mr. A. Bement of Chicago gives data of analysis of products of combustion from an oxygen calorimeter, which show an error in results due to presence of CO amounting to about 2 per cent. of the total heating value of the fuel. In a high-grade bituminous coal that would amount to about 300 British thermal units. If unburned hydrocarbons were also present, the error would be still larger. Would it not be well to investigate this source of error?

It would be useless for me to protest that I am not proposing to supersede all other coal calorimeters by the Berthier method. It is simply *one* of the ways of ascertaining the heating value of coal. And if the proposed corrections to its formula are accepted, I am at present inclined to think it will compare well in substantial accuracy of results with either the oxygen calorimeter or ultimate analysis.

The name of the oxygen calorimeter referred to in this paper is withheld (1) because it does not seem desirable for members to make the Proceedings of the American Society of Mechanical Engineers a medium of praise or blame for each other's wares; and (2) a user of a later form of the calorimeter tells me it has been improved.

No. 839.*

A NOTE ON FLYWHEEL DESIGN.

BY A. J. FRITH, NEW YORK CITY.
(Member of the Society.)

AT a previous meeting of the Society, a fellow member presented us with a drawing of a band flywheel, which had a rim of cast iron with shallow cross ribs, meeting in a pad on the under side, to which the arms were bolted.† This wheel had accidentally been run up to an unusual speed, and was afterwards found to be out of true. Upon examination it was discovered that about 50 per cent. of the intersections of the arm pads and ribs on the rim were cracked around the entire wheel. In the discussion which followed, I felt called on to maintain that it was most remarkable that a cast-iron structure could practically start to give way at almost every point, and still keep its integrity, and it still seems to me to be owing largely to the effort of the material not to part destructively, but to assume a form in which all its particles would be more equally strained. It was then suggested that perhaps we had not sufficiently considered the effect of the arms of a flywheel on its rim, when affected by centrifugal force, and that there might be something more to be considered in the designing of flywheels than is ordinarily laid down in our text-books regarding the mutual proportions of arms and rim. Subsequent consideration has only strengthened the views then expressed, and I would now beg to lay before the Society a brief statement of what seems to be the cause of the accident related to us, and to suggest a possible remedy for it.

In designing a flywheel, it is customary to calculate the weight of the rim to fulfil certain conditions of diameter, and

---

* Presented at the New York meeting, December, 1899, of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

† Mr. James McBride, Discussion of "Bursting of Small Cast-iron Flywheels," vol. xx., page 236.

revolution of the wheel to obtain a limited variation of speed fixed by the load and duty of the engine.

The arms of the wheel may be calculated as beams loaded at one end with forces which may be approximately determined by the maximum, and its possible widest variations of speed—conditions that vary so radically with the character of the work devolving upon the engine as to allow for wide latitude in proportion. It has also been advised to figure the section of arms to withstand the tension which would be produced if the entire centrifugal effort of the rim and arms were transmitted to the arms, a duty which it is evident they are never called upon to perform.

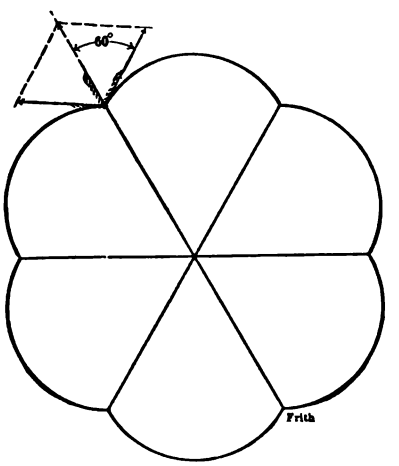


FIG. 69.

For to do so the line of rim tensions would have to be so modified as to develop a radial effort equal to themselves, and they would have to make an angle (a) of 60 degrees with the arms, as shown in Fig. 69.

It is hard to suppose that any cast-iron wheel whose rim was originally circular, no matter how thin and flexible it might be, could assume such a form without being destroyed. Nor could such a form be possible unless the rim should be stretched much more than the arms, and this assumes that the unit strains in the rim are larger than in the arms of the wheel.

Hence if the arms of a wheel are made of such a section that they will withstand the centrifugal effort of the wheel, they will probably not accommodate themselves to the extension of the

rim, and especially in a band wheel with a light flexible rim, will tend to draw it in, and cause fractures at exactly the location where they did occur in the example already laid before us.

On the other hand, if the arms be so proportioned and so loaded that they will have the same unit strains as the rim, then they should extend to the same scale, so to speak, and there should be no tendency for the rim to be disturbed or lose its circular form, and fractures such as those shown us by Mr. McBride should not be expected to occur.

Let W = the weight of unit of material.
o = angular velocity.
R = radius of the wheel in feet.
f = the tension in the rim due to centrifugal force.
c = the tension of an arm due to a unit of its own weight.

Then

$$f = \frac{W}{g} o^2 R^2, \text{ and}$$

$$c = \frac{W}{g} o^2 R$$

$c = \frac{f}{R}$, or the strain induced in the arm by the centrifugal force of a unit of its own weight is but $\frac{1}{R}$ times that of the rim tension, and this decreases as the position of the unit nears the centre. The units near the centre must, however, also withstand the pull of those further out, so that the final average tension in the arm is about 35 per cent. of that of the rim tension per square inch. As the nave is, however, massive in construction, I have taken the average tension per square inch in the arm of a flywheel as 30 per cent. of the unit tension in the rim, though this will vary with different diameters of wheel.

The above is tension developed by centrifugal force in the arm by its own weight, and is independent of its actual section. As it is considerably less than the rim tension, it appears impossible to have the arms stretch in unison with the rim, by its own weight alone, no matter how we may proportion it. But how can we throw extra effort on it without destroying the rim, when as in Fig. 69 the shape of the rim which transmits its tension to the arm is far from circular? Can we not make part of the

rim circular, and part as shown in Fig. 69, proportioning this second part with such a section that the arms will have an extra tension thrown upon them sufficient to bring the unit strains up to those of the rim sections?

In Fig. 70 I have shown a sketch that embodies this idea.

The arms are to be made to withstand the strains which would be developed by the particular service the wheel is called upon to serve; that is, to drive the wheel, and to withstand the varia-

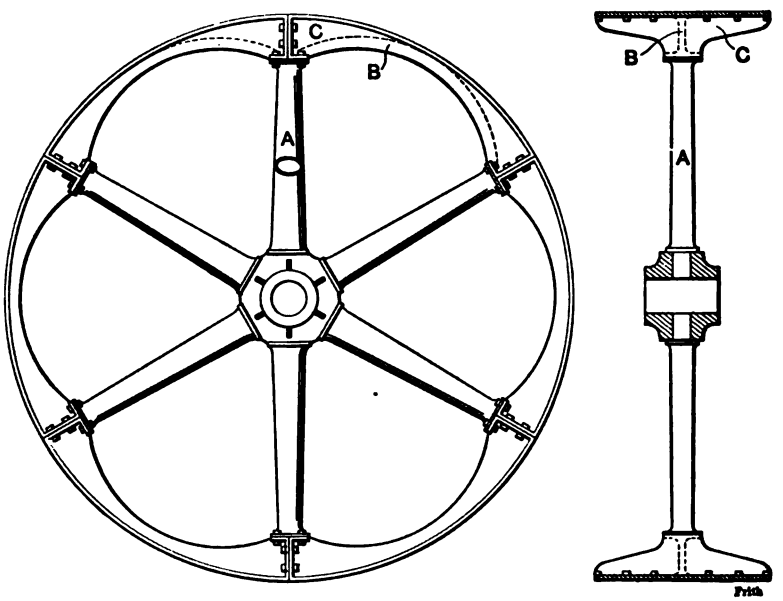


FIG. 70.

tion of speed without undue deflection. For this purpose the metal should be arranged in a section which gives the greatest rigidity with the least section, hollow arms and oval sections being particularly well adapted for the purpose. The weight of the total rim is figured to meet the condition of diameter, speed, and variation of speed desired.

Of this total weight of rim part is circular as shown, and a part is arranged in arches between the arms, drawn to coincide with the natural catenary curve which the particles would take if free to arrange themselves to the forces induced. This curve is believed to be an ellipse, and is drawn to make an angle of 60 degrees with the arms.

The section of the metal in this arch we will call B in square inches.

There is a further amount of metal at the end of the arm and between the circular and arch curves, which practical considerations and methods of fastening make necessary. This includes the bolts and flanges of both arms and rim sections, and we will call it C, and express it in cubic inches of metal.

Let the section of arms already determined be called A in square inches. I would suggest the following formula in a six-armed wheel for finding the section of the arch, whose rise is one-fourth of the radius.

$$B^{\text{sq. in.}} = 70\% \; A^{\text{sq. in.}} - \frac{C^{\text{cu. in.}}}{\text{Radius in inches}}.$$

From which we see how much less efficient is the material placed at the ends of the arms than that placed in the arch.

To insure that the stress should follow the line of the several arches, and not pass directly and parallel to the outer rim, openings in the metal at C will probably be advisable.

It is believed that this method of reinforcing the rims of band flywheels in particular would obviate such accidents as that mentioned, and it has a particularly good feature in the depth of section immediately over the arms, where there should be no difficulty in providing a fastening of bolts whose total area would be sufficient to balance the total rim tension in the wheel, a condition which is so difficult to obtain under present conditions, although its necessity has been dwelt upon by every one who has treated and discussed the subject before us.

In the sketch the size and number of bolts shown, as well as the flanges, are not to be criticised, as no effort was made to proportion them to the probable strains; there does not seem to be any difficulty in providing *lugs* which would be sufficient.

The rise of the arch B might also be reduced, though the section of B would then be larger than that given in this paper.

The cross rib at the parting over the arm can be made the full width of the face, and deep enough to carry the centrifugal force of its own weight and transmit it directly to the arms; hence its presence can have no ill effect upon the rim however much it may extend beyond the arms.

Whether such a wheel can be made to compete commercially with those of present construction remains to be seen. Those

who have suffered from the effects of a bursting flywheel will probably have a sufficiently healthy respect for its powers of destruction to pay what is necessary to prevent its recurrence.

DISCUSSION.

Mr. Frith.—I might add, in discussion, that we have built some flywheels on this plan—that is, not very large ones—and that their appearance is exceedingly pleasing; the distribution of metal, etc., in the beams impresses the eye as being excellent.

Mr. Charles T. Porter.—I had notified the Secretary that I would make a few observations on Mr. Frith's paper, which is entitled "A Note on Flywheel Design," but I find the paper is limited to *small* flywheels. I want to state frankly that I think that all minute construction of this character is out of place altogether on the small flywheel; that it is only a question of proper construction of a good solid wheel, that the difficulties that really arise are almost universally from unequal shrinkage and internal stresses in the castings, that when wheels are made of light section they cool quickly and are very liable to internal stress, but when they are made of heavy section, unnecessarily heavy, if you please, and cooled slowly, they are sure to be quite free from internal stress, and under those circumstances we never hear of such a thing as a flywheel bursting. There is always a good reason for their bursting, and I think when they burst they are made to burst, designed to burst—not intentionally, but none the less actually designed to burst.

So far as small flywheels are concerned, I have had considerable experience with running at high speeds, running one engine regularly at 450 revolutions a minute, and I never had any trouble with flywheels. I had one wheel, 21 feet in diameter, making 125 revolutions per minute, run away at the mill of the National Tube Works, and Mr. Matheson, the superintendent, ran out of the room as fast as he could. He expected it to fly all to pieces, but it did not.

I received my first lesson in large flywheels at the Cambria Iron Works. I put in an engine for their rolling-mill and they made their own flywheel, and when I saw it I found they had made it on a plan that had been left to them as a legacy by Mr. Fritz—casting the rim in a single piece and the arms as a spider, and putting them together in a manner that has already been

described, I think, by Mr. Fritz—put together in very elegant fashion, so that there was sure to be no internal stress in the whole business, and it could be run at any speed within reason safely enough. The engine could run at three or four times its intended speed before the flywheel would burst. I think if proper designs are followed in making flywheels, and proper pains taken in using strong iron and large, thick sections, and cooling them slowly, there will be no trouble. Often wheels for small engines are made of very thin sections, and they will cool quickly and unequally, and are liable to crack, especially if they are designed with nice corners where cracks can take place.

Mr. Gus C. Henning.—I would like to say a few words about Mr. Frith's design in which he bolts up the rim to flanges on the arms. The corner of that flange is likely to have shrinkage cracks, and as the forces are centripetal, there might be some bending stress in that corner, producing strains. It might be modified so as to avoid those difficulties, if the arm were carried right through; it could then be bolted through, and the bolts would be in shear alone, and there would be no such corner. This modification would tend to make the wheel readily and cheaply made. The rim could be put into a casting roughly, and then planed out parallel, and the spider put on the planer in the same way and the opposite ends planed off the same way and then fitted in and the bolts put through. Because the bolts must be in shear and the arm is always in tension, the centrifugal force not coming into play except in starting or stopping or in case of the sudden arrest of the wheel, it would avoid this danger point of the fillet corner. Such flange is also dangerous for another reason—in case the rim does not fit the flange accurately it will produce a stretch in the corner which may produce a serious stress. The centripetal force, of course, will tend to do the same, produce tension in the fillet, and the arms may tend to bend the flanges up and increase the stress in the corners.

Prof. Gaetano Lanza.—I cannot see what is the special advantage of this peculiar construction. Of course, the greatest bending moment in the rim of a flywheel usually occurs at its junctions with the arms, where the author of the paper has provided the largest section, but were the wheel built in the way described, I do not think that the stresses would be those assumed by him, even if it were permissible to leave out of account the important question of initial strains.

The principal causes for the failure of large flywheels are poor design and poor castings.

It is well known that a great many flywheels have been built in whose design all consideration was omitted of the bending stresses in the different portions of the rim; and inasmuch as these stresses are among the most important ones, it is no wonder that many flywheels so designed have burst.

It would hardly seem necessary to emphasize the fact, that in designing a flywheel we should take pains to figure the stresses in all parts of the rim, not only those due to direct tension, but also those due to the bending of the rim as a whole, and also those due to the bending of the separate parts, as the flanges, bolts, etc. That this is true is known and appreciated by many to-day, but it has had to be learned by some by sad and costly experience. Of course the chief interest, it seems to me, with regard to the bursting of flywheels rests with the large flywheels; and in these the face is usually so wide that there is such a large overhang of the rim beyond the arms that the stresses at the outer edges of the rim are entirely different from what they are near the arms.

Mr. William Kent.—I understand that Mr. Frith's plan of strengthening the rim of the wheel deeper is to make it of a form similar to that of a beam of uniform strength fixed at the ends. Other designers, after they find the proper section through the weakest point in a rim of uniform thickness—that is, the ends—make this section uniform throughout. That makes a beam of uniform section, not of uniform strength. Years ago it used to be the fashion to make beams of uniform strength; but modern practice is to make beams of uniform section which are weakest at a certain point, to make them strong enough at that weak point and get an excess of strength at other points. I think modern design tends to increase the depth at the ends, to gain strength, but also to increase it uniformly, and that the extra metal halfway between the arms is valuable for the very purpose for which a flywheel is designed—that is, the equalization of energy—and this extra amount of metal probably is not destructive enough from its centrifugal force to exert a bad influence at that point. One of the best wheels I ever saw was two feet across the face and one foot thick, a solid chunk of iron. Other and lighter wheels in the same place had broken, so this one was made enormously heavy, and I think that is the modern tendency.

*Mr. Frith.**—I should like just briefly to reply to some of the criticisms made on my paper. Referring first to Mr. Henning's, his remark with regard to the lugs on the end of the wheel is certainly well taken, but hardly fair. I would call his attention to the mention in the paper that criticism should not be made, because it was simply a sketch attempting to show the theory, not the details of construction. We all know perfectly well that a shallow lug of that kind would be very apt to part in the corner, and the paper mentions if made in practice it would undoubtedly be made so deep that any idea of its parting where it is joined to the arm would be eliminated. We would naturally make our details a great deal stronger than their fastenings to the rim.

I should also like to correct the remark made by Mr. Porter that the idea was to apply the theory to small wheels. I certainly did not say anything of the kind. My meaning was simply that I had tried it on a small wheel, but that the whole discussion was meant to apply to larger flywheels and especially to band flywheels.

In the case of flywheels of heavy section the remarks that have been made with regard to shrinkage strains, etc., are well enough. We all know that great attention must be paid to modelling the sections so that these internal strains, etc., should not enter, and where the sections are very large, why the evils that I was attempting to remedy apply to a much lesser extent. But in the case of this wheel that Mr. McBride spoke of and which is one of a class that I refer to in my paper, the sections of the wheel are very light, and from all the ribs in the wheel parting when it was run at an unusual speed it certainly showed that there was a tendency in that broad rim to assume a shape other than a circular one, and that the result of that tendency was to let the ribs part completely around the rim. That is, there were over 50 per cent. of the stiffening ribs that parted. Now it is hardly to be supposed that in a cast-iron structure 50 per cent. of the fastenings can start and give way and the wheel not go to pieces. I take it that it was an effort of the wheel to assume the curved section between the arms, and that with a rim that was so light, as soon as those ribs parted it assumed a shape that may have been pretty stable, but unfortunately was not round, and therefore was not in a condition to drive a belt.

---

* Author's closure, under the Rules.

Professor Lanza and Mr. Kent both maintain that the bending of the rim at the arms should be resisted by sufficient material, and testify to the very evils I have pointed at, which is gratifying, but it still seems to me that it would be better to eliminate the strains, in preference to resisting them. It is possible to make rims so heavy and put in so many arms as to render breakage unlikely, in fact build a wheel of the same proportions as a grindstone, but such wheels would hardly be commercial ones, and it is of commercial wheels that we are speaking. Engineers well know that bending or cross strains in a tension member, especially of cast-iron, are exceedingly dangerous because practically indeterminate. Professor Lanza to the contrary notwithstanding, the theory here advanced is that by loading the arms with the weight of a known part of the rim, the arms can be made to stretch with the rim. When we do that, we care not how wide the face of the wheel—the rim remains circular, and there are no cross strains to be taken care of. Flywheel rims are figured as if they were a ring, and unless we make provision for the figure being maintained when under strain, our calculations are deceiving and dangerous.

No. 840.*

TEST OF TWO TEN-MILLION-GALLON PUMPING ENGINES AT THE BADEN PUMPING STATION, ST. LOUIS WATER WORKS, JUNE, 1899.

BY JOHN A. LAIRD, ST. LOUIS, MO.
(Member of the Society.)

THE engines tested are duplicates, built by the Edward P. Allis Company, and are of the now well-known type of Reynolds pumping engine which all of the large builders have adopted. They are three-cylinder triple-expansion, condensing, vertical, with rigid connection between plungers and pistons, three single-acting plungers. The diameters of cylinders are, respectively, 30 inches, 54 inches, and 80 inches. The plungers are 25½ inches in diameter, and all are 64 inches stroke. There are two receivers, the heating coils inside of which are helical and extend for the full length of the receivers. The cylinders are jacketed on the sides, but not on the heads. The jackets, cylinder heads, receivers, and all other heated surfaces about the engines are covered with 2 inches of magnesia and 2 inches of hair felt; the whole enclosed in walnut lagging.

The distribution of steam through the jackets and receivers is shown in Fig. 71. This system has the effect of reducing the amount of jacket steam by a small percentage. The steam-distribution valves are all Corliss except the low-pressure exhaust, which are poppet. The clearance on high-pressure cylinders is 1.036 per cent.; on the intermediate, 1.18 per cent., and on the low, .509 per cent.

According to accepted practice on triple-expansion pumping engines, the governor only controls the cut-off on the high-pressure cylinders, the others being regulated by hand. There are two piston rods to each cylinder, packed with Tripp's metallic packing. They connect to an Allis four-cornered cross-head, to the

---

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

centre of which is attached the connecting rod, and to the corners the four pump rods. The piston rods are each 4 inches in diameter, and the pump rods, 4½ inches. The pump barrels are directly underneath the steam cylinders, and the valve chambers are on the centre line of the engine. The plungers are single acting. The pump valves are 3½ inches in diameter, have a ⅜-inch lift, and are placed on cages with 20 valves on each cage. There are 7 cages on each diaphragm, and the free water-way through the valves on any one diaphragm is about equal to the area of the plunger. The bedplates, carrying main-shaft pillow blocks, rest on masonry piers. The suction pipes run through the engine-pit wall to a wet-well from which all six of the engines in the house

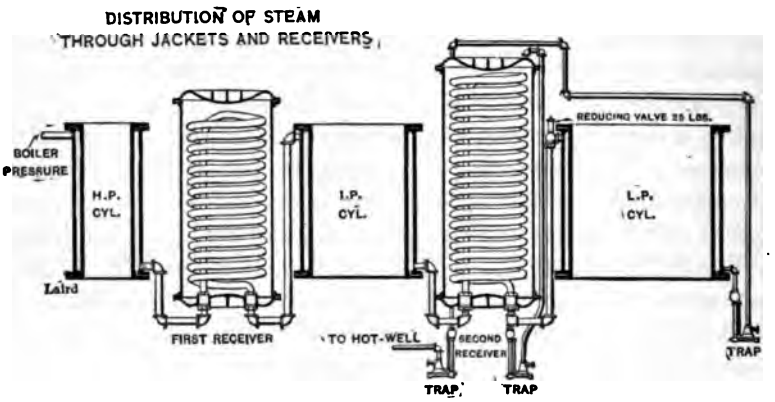


FIG. 71.

will draw. The level of water in the wet-well was about 17½ feet above the bottom of the pumps during the test, making about 13 feet of head on the suction valves. This suction head was practically constant, and the discharge head did not vary more than one-half of 1 per cent. above or below the mean.

All of the auxiliary pumps required to run the engine, as the feed pump, air pump, and air compressor for charging the air chambers, were attached to, and run by, the main engine during the test. The circulating water was taken from the suction pipe and returned to the same, as shown in Fig. 72.

Boiler Plant.

The boiler plant for the station consists of eight 300-horse-power boilers of the water-tube type, manufactured and furnished

by the John O'Brien Boiler Works Company, of St. Louis. The boilers each have 3,000 square feet of heating surface and are equipped with the Hawley down-draught furnace. The upper grate has 37.6 square feet of surface and the lower 50.3 square feet. The stack is 150 feet high, with 7 feet internal diameter. The smoke connection to stack is sheet iron, overhead, and covered with magnesia blocks and canvas. Fig. 73 shows a general plan of the station.

Figs. 74 and 75 show the arrangement of tanks, piping, and scales used in weighing the water during the tests.

The water was weighed twice; that is, all of the water fed to the

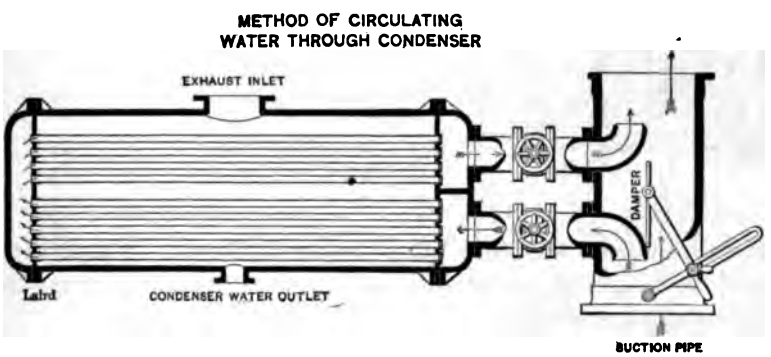


FIG. 72.

boilers was weighed in the boiler-room tanks Nos. 5, 6, and 7, and all of the condensed steam, separator, and calorimeter water was weighed in the engine-room tanks Nos. 1, 2, 3, 4, 8, and 9. The total water weighed in the boiler room should equal that weighed in the engine room, when corrected for water level, leakage, and other losses from the system. This check was figured in two ways: First, total water sent from boiler room must check with total water received in engine room; Second, the water being used over and over, the total water sent from engine room should equal that received in boiler room. The engines being surface condensing, it was possible (theoretically) to account for every pound of water which came into the engine room.

The greatest care was taken to pipe all drips, as valve bonnets, piston-rod packing, etc., to the tanks, so that all leaks of this character should be charged against the engine. The steam pipes and all other pipes running to the engines to be tested were cut

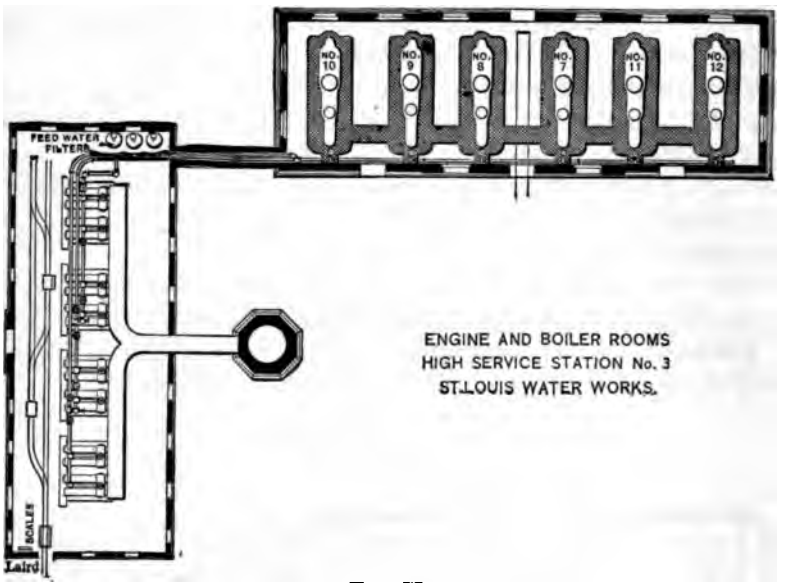
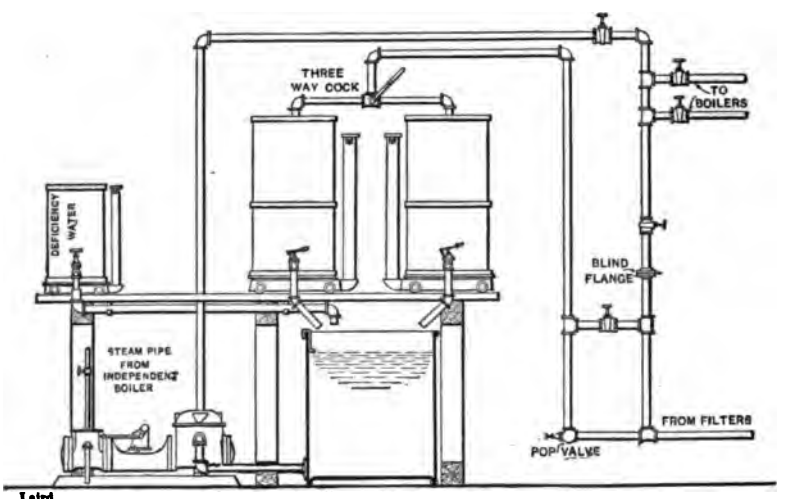


FIG. 73.

off entirely from all other pipes in the buildings, so that there could be no possibility of water getting into the system from any other source, or losing any.

How well this was accomplished is proven by the results of the



ARRANGEMENT FOR WEIGHING FEED WATER

FIG. 74.

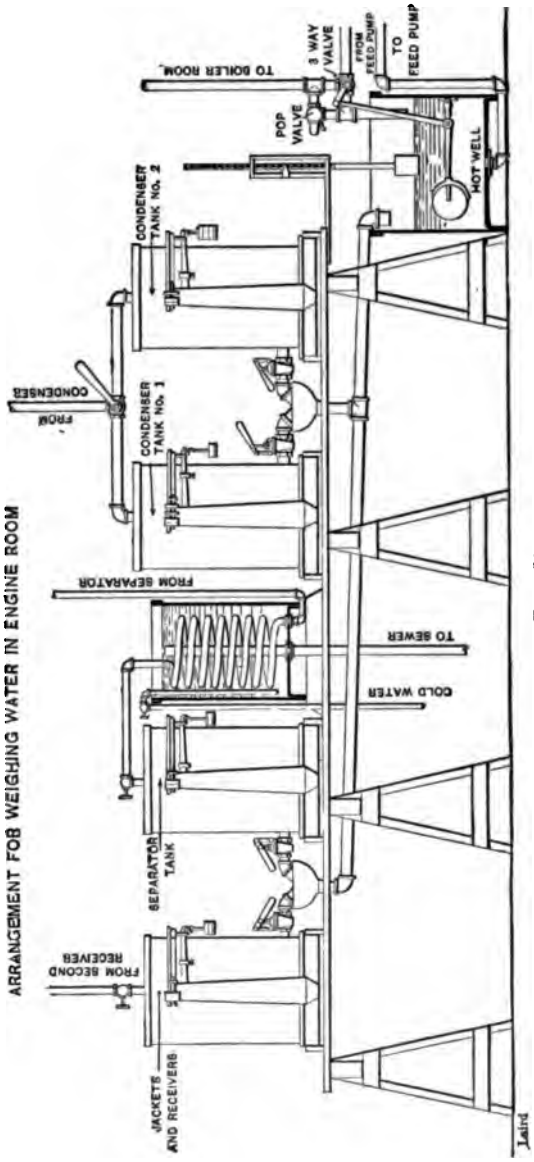

ARRANGEMENT FOR WEIGHING WATER IN ENGINE ROOM
TO BOILER ROOM.
3 WAY VALVE
FROM FEED PUMP
TO FEED PUMP
POP VALVE
HOT WELL
CONDENSER TANK No. 2
CONDENSER TANK No. 1
CONDENSER FROM
FROM SEPARATOR
TO SEWER
COLD WATER
SEPARATOR TANK
FROM SECOND RECEIVER
JACKETS AND RECEIVERS
Laird

FIG. 75.

two twenty-four-hour tests, in which the total water weighed in the engine room differs from the amount weighed in the boiler room by only about $\frac{1}{10}$ of 1 per cent. of the whole amount weighed in either place.

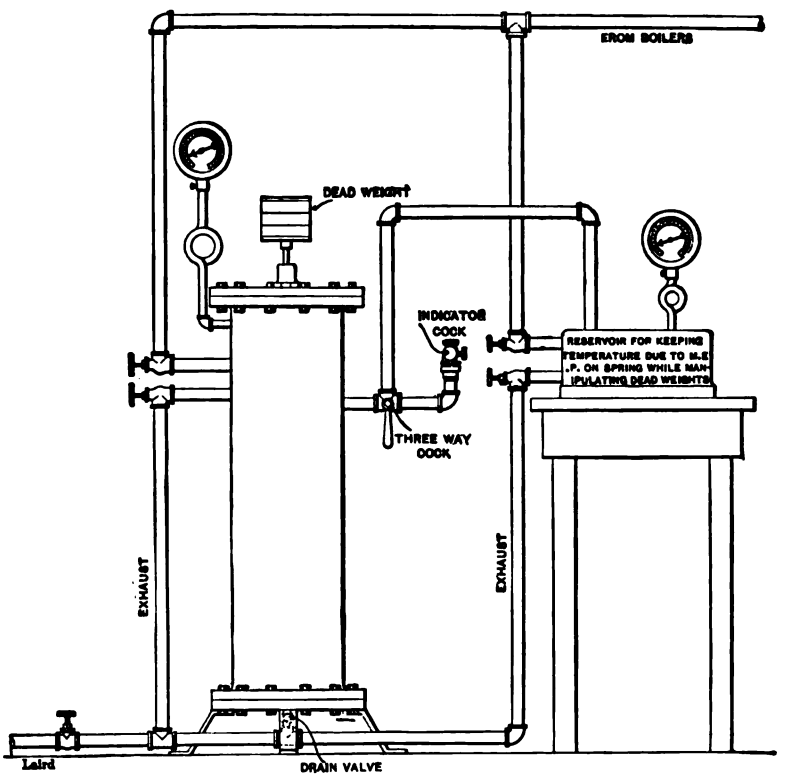
As the contract duty was not based on thermal units, and in order to prevent any loss by evaporation, the trap discharges from second receiver and low-pressure jacket were run through cooling coils, and brought down to a temperature at which there was practically no vapor given off. A twenty-four-hour leakage test on the boilers and piping was made both before and after the official duty trials. The conditions of pressure, etc., were kept as nearly as possible the same during the leakage tests as the duty tests. It was found that the boilers lost more water during the second leakage test than the first, and it was assumed that the increase in leakage was uniform during the time which elapsed between the two tests.

Owing to the difficulty of cutting out a single boiler from the system, two boilers were connected with the steam main running to the engines being tested. One of them did all of the work, while the other was run with banked fires. This condition, of course, made the boiler test of no value, and the duty figured on a coal basis is accordingly much lower than it would be under ordinary working conditions.

As may be seen on the plan of the station, the coal is brought into the boiler room on charging cars. These cars are of one ton capacity and run on cast-iron tracks—the C. W. Hunt system. All the coal is weighed on small track scales as it is brought into the house, and the ashes are weighed as they go out. The coal used was Illinois, run of mine, from the Belleville district. It runs 13 to 14 per cent. ash and about 11,000 British thermal units per pound. The cost of the coal, present contract, is \$1.18½ per ton, unloaded in the coal house.

All of the apparatus used on the tests was carefully compared with reliable standards, most of them both before and after the tests. Pressure gauges were tested with a Crosby dead-weight apparatus; scales were tested by U. S. standard weights. The thermometers were compared with the Hicks standard thermometer No. 855,952, verified at the Kew Observatory. The indicators used were the Crosby, with the electro-magnetic attachment for taking simultaneous cards. The indicator springs were calibrated with a special dead-weight apparatus, shown in Fig. 76,

by means of which, working conditions, in temperature and pressure, are very nearly obtained. The indicator-spring tests were made so carefully and satisfactorily that the pressures taken from the cards were used in preference to those read from the gauges, on account of the water column on nearly all of the gauges and the difficulty of correcting for it.



APPARATUS FOR TESTING INDICATOR SPRINGS

FIG. 76.

The suction head was determined by a gauge in the well, read in elevation above the city datum, and the discharge head was read from a mercury column, the zero of which was an even number of feet above city datum. The scale on the mercury column was graduated in feet of water and corrected for temperature.

The stroke and diameter of the plungers were very carefully

measured with a standard Chesterman steel tape. The diameters were obtained by measuring the circumference of plungers at top, bottom, and middle, and averaging them. The stroke was obtained by putting each crank on its dead points and measuring the extreme travel of a line on the cross-head shoes.

The test on each engine was of 24 hours' duration. That on No. 7 commenced at 8 A.M., June 6th, and ended at 8 A.M., June 7th. The one on No. 8 commenced at 9 A.M. on June 9th, and ended at 9 A.M. June 10th.

As before stated, very little attention was paid to the boiler test; but as it was desired to check the weighings through the boilers, it was necessary to ascertain the amount of water in the boilers at the beginning and end of the test, with the greatest possible accuracy. After trying several different methods, it was decided to start the water running through all of the tanks some hours before the test was to be started, keeping the amount of water in the system, but outside of the boilers, constant. During this time the only things which would cause the water level to change, were the condition of the fires and the leakage.

One hour before starting the tests, the fires were cleaned and levelled up so as to have a bed of coals of uniform thickness all over the grates. Fifteen minutes before the test was to be started, an observer was stationed at each water gauge, and the level was read on a fixed scale every ½ minute until the test was started, and the mean of these readings taken as the initial water-level. The above conditions were duplicated at the close of the test, only that the ½ minute readings were taken for 15 minutes after the test was closed, and the mean taken as the final level. Theoretically, the level was incorrect by an amount equal to the leakage for 15 minutes, about 25 pounds, which is well within our limit of error.

During the tests the water-level was read every 30 minutes, for the purpose of making checks through the boilers; a complete check being made each hour. In order to get simultaneous readings, electric bells were located in the boiler room, on the main floor of the engine room, and in the pump pit, with a controlling button in front of the Howard engine-room clock. Two bells were given one minute before the hour and one on the even hour.

According to the contract the amount of water pumped was determined by the displacement. The weight of a cubic foot of

water used in the computations was taken from Clarke's tables. The discharge head was reasonably constant, but as there was an irregular variation of two or three feet of water, it was thought best to read the mercury column on the discharge pipe every 5 minutes, and the mean of these readings was taken as the average head pumped against. The suction gauge, being very steady, was only read every 30 minutes. All other general observations were taken every 30 minutes. A complete set of indicator cards was taken every two hours. Samples of the cards are appended herewith, also combined steam cards.

The contract provided that the tests for duty and capacity should be made by three experts; one to be selected by the Water Commissioner, one by the builder of the engines, and the two thus selected to name the third. The writer was named by the Water Commissioner to represent the city, Mr. Arthur West was named by the Allis Company, and Mr. M. L. Holman was agreed upon to act in the capacity of the third expert.

A word might be said here of the observers on these tests. There were 15 of them, all employees of the Water Department, and with three exceptions have taken part in all of the duty trials which have been made in the St. Louis Water Department for the last ten years. Among the most important which they have taken part in are the two 30-day tests on the 20-million Worthington engines, Nos. 4 and 5; two 30-day tests on the Allis 30-million engines, Nos. 6 and 7, and two 30-day tests on the two 30-million Allis engines, Nos. 8 and 9—all at the Chain of Rocks. The writer does not know of a corps of observers anywhere who have had anything like the experience on duty trials that these men have had.

The contract requirements were: Sec. Q., "Each engine furnished under the contract shall have a pumping capacity of 10,000,000 United States gallons in 24 hours. The capacity to be at a speed that will insure smooth and quiet action, and to be determined by the experts during the duty test." Sec. R., "It is further agreed that the pumping engines furnished under this contract, shall perform, during a running test of 24 hours, a duty of 125,000,000 foot-pounds per 1,000 pounds of commercially dry steam." The contract also provides for a bonus to be paid, in the ratio of $1,000 for each million foot-pounds the duty goes above 125,000,000, and a forfeiture of $2,500 for each million that it goes below 125,000,000.

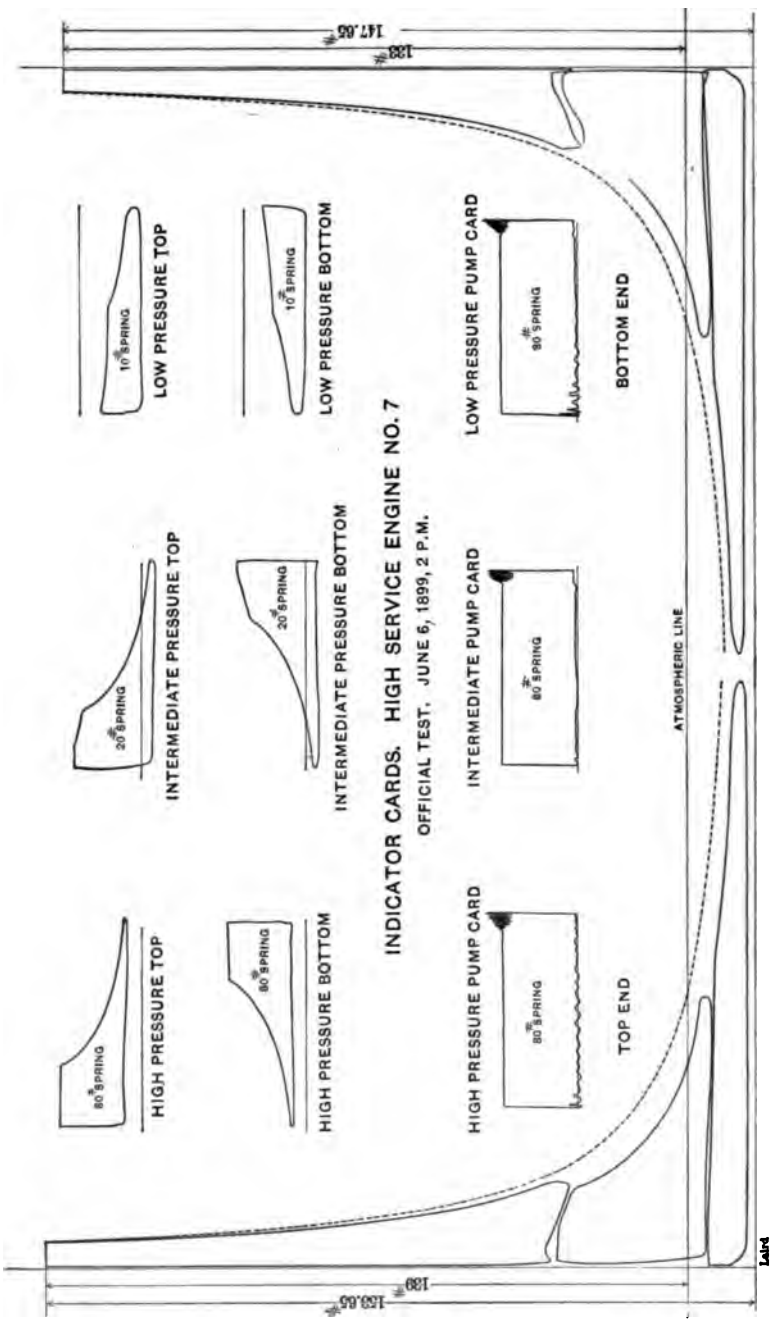

INDICATOR CARDS. HIGH SERVICE ENGINE NO. 7
OFFICIAL TEST, JUNE 6, 1899, 2 P.M.
HIGH PRESSURE TOP
80 # SPRING
HIGH PRESSURE BOTTOM
80 # SPRING
INTERMEDIATE PRESSURE TOP
20 # SPRING
INTERMEDIATE PRESSURE BOTTOM
20 # SPRING
LOW PRESSURE TOP
10 # SPRING
LOW PRESSURE BOTTOM
10 # SPRING
HIGH PRESSURE PUMP CARD
80 # SPRING
INTERMEDIATE PUMP CARD
80 # SPRING
LOW PRESSURE PUMP CARD
80 # SPRING
TOP END
BOTTOM END
ATMOSPHERIC LINE
128
128.66
147.66
Laird

FIG. 77.

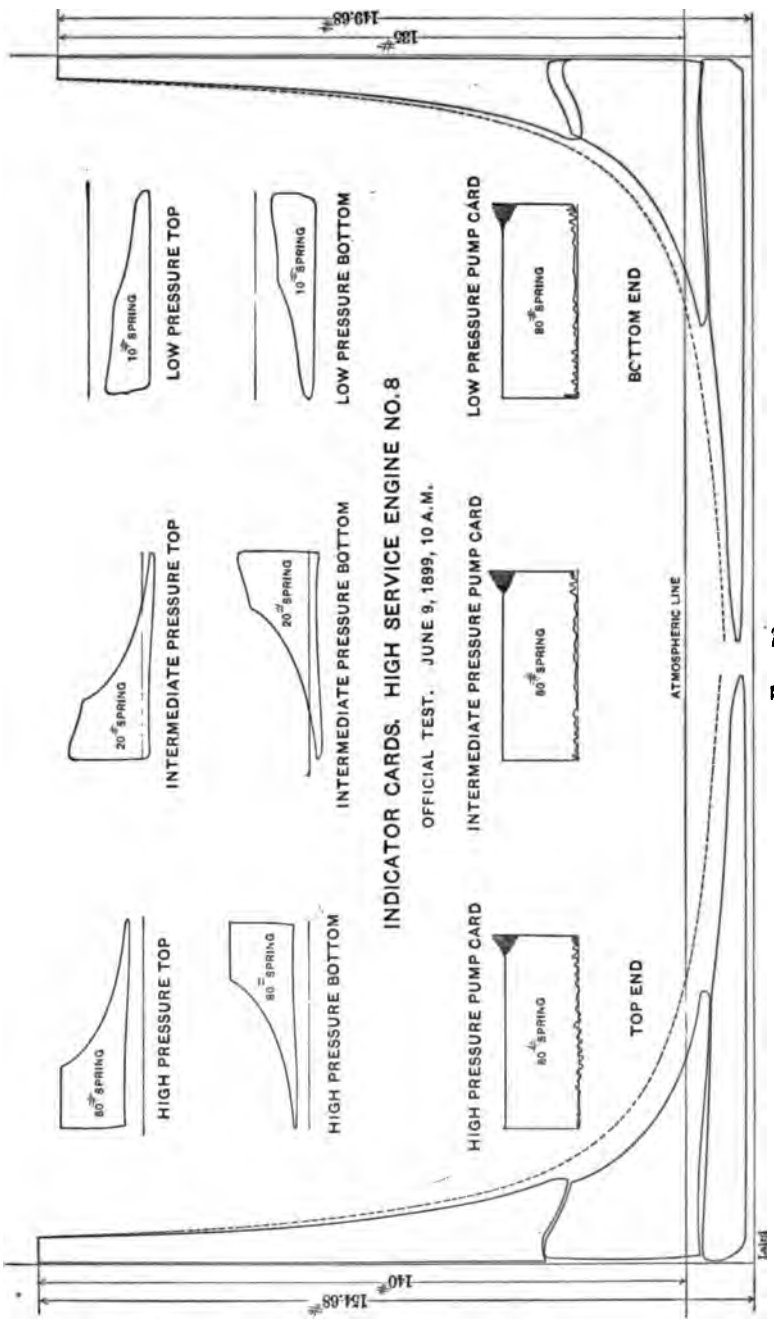

INDICATOR CARDS. HIGH SERVICE ENGINE NO.8
OFFICIAL TEST. JUNE 9, 1899, 10 A.M.
HIGH PRESSURE TOP
80" SPRING
HIGH PRESSURE BOTTOM
80" SPRING
INTERMEDIATE PRESSURE TOP
20" SPRING
INTERMEDIATE PRESSURE BOTTOM
20" SPRING
LOW PRESSURE TOP
10" SPRING
LOW PRESSURE BOTTOM
10" SPRING
HIGH PRESSURE PUMP CARD
80" SPRING
TOP END
INTERMEDIATE PRESSURE PUMP CARD
80" SPRING
ATMOSPHERIC LINE
LOW PRESSURE PUMP CARD
80" SPRING
BOTTOM END
154.08"
140"
125"
149.08"

FIG. 78.

The general formula used for work and duty is as follows:

$$\text{Foot-pounds} = \frac{Rhw}{\pi \times 4 \times 12 \times 144}\left[(\pi d_1)^2 S_1 + (\pi d_2)^2 S_2 + (\pi d_3)^2 S_3\right].$$

$$\text{Duty} = \frac{Rhw}{1{,}728}\left[\frac{(\pi d_1)^2 S_1 + (\pi d_2)^2 S_2 + (\pi d_3)^2 S_3}{4\pi}\right]\frac{1{,}000}{\text{Steam}}.$$

R = number of revolutions, h = total head, w = weight of one cubic foot of water, d_1 = diameter of high-pressure plunger, d_2 = diameter of intermediate-pressure plunger, d_3 = diameter of low-pressure plunger, S_1 = stroke of high-pressure plunger, S_2 = stroke of intermediate-pressure plunger, S_3 = stroke of low-pressure plunger, and Steam = total amount of steam chargeable to engine, in pounds.

Indicator Card Data.	7		8	
	Top.	Bottom.	Top.	Bottom.
Area of high-pressure piston.....	706.86	678.49	706.86	678.49
" intermediate " 2,290.2	2,261.83		2,290.2	2,261.83
" low-pressure " 5,026.5	4,998.13		5,026.2	4,998.13
High-pressure Cards.				
Scale of spring (nominal).....	80	80	80	80
" " (actual).....	78.82	79.366	78.82	79.366
Admission pressure (absolute)....	153.85	148.25	153.88	150.48
Cut-off " "	153.65	148.15	153.68	150.4
Release " "	44.4	41.4	43.98	41.48
Compression " "	87.35	62.65	82.68	78.48
Per cent. of cut-off.....	29.19	28.50	29.4	28.1
Mean effective pressure.....	55.6	54.1	55.25	53.95
Indicated horse-power.....	104.35	96.93	103.75	97.04
" " (total).....	201.28		200.79	
Intermediate-pressure Cards.				
Scale of spring (nominal).....	20	20	20	20
" " (actual).....	19.493	19.206	19.493	19.21
Admission pressure (absolute)....	43.30	43.35	44.28	43.78
Cut-off " "	38.25	37.50	38.88	38.38
Release " "	11.73	10.38	11.37	11.61
Compression " "	28.49	12.73	22.48	17.56
Per cent. of cut-off.....	29.25	29.00	28.5	28.5
Mean effective pressure.....	15.43	15.38	14.89	15.38
Indicated horse-power.....	93.51	92.02	90.53	92.29
" " (total).....	185.53		182.82	

Low-pressure Cards.	7		8	
	Top.	Bottom.	Top.	Bottom.
Scale of spring (nominal).....	10	10	10	10
" " (actual)	9.87	9.795	9.87	9.795
Admission pressure (absolute)....	10.27	10.61	11.03	10.83
Cut-off " "	8.425	8.97	9.06	9 17
Release " "	4.98	4.29	4.76	5.18
Compression " "	5.42	5.64	6.10	4.98
Per cent. of cut-off.....	52.8	52.5	45.6	45.6
Mean effective pressure.....	6.115	6.04	6.112	6.02
Indicated horse-power.....	81.48	80.42	81.53	79.79
" " (total).....	161.90		161.32	
Total horse-power, 3 cylinders..	548.71		544.93	

REPORT OF DUTY TESTS ON HIGH SERVICE ENGINES NOS. 7 AND 8.
St. Louis Water Works.

	7	8
Engine number.....		
Date of test.....	June 6 and 7	June 9 and 10
Duration of test.....	24 hours	24 hours
Pressures.		
Steam pressure in engine room, from cards, lbs.	136.	137.
First receiver, from cards, lbs.....	27.3	28.5
Second receiver, from cards, lbs	4.0	3.0
Vacuum, from cards, lbs.....	13.14	13.03
Barometer, inches.....	29.59	29.67
Temperatures.		
Water pumped, deg. Fahr.....	79.0	76.8
Feed-water, " "	103.2.	99.3
Air pump discharge, " "	95.0	94.6
Circulating water, in, " "	79.0	76.8
Circulating water, out, " "	94.0	94 0
Exhaust, " "	115.6	113.5
Air, engine room, " "	85.9	75.3
Air, outside, " "	86.6	68.3
Feed-water and Steam.		
Total water fed to boilers, lbs.....	153,398.	152,402.
Water fed to boilers per hour, "	6,391.6	6,350.
Quality of steam at throttle, per cent.....	99.8	99.8
Total dry steam to engine, lbs.	153,122.	152,128.
Dry steam to engine per hour, "	6,380.8	6,338.7
Total water from surface condenser, "	133,251.	132,227.
Water from surface condenser per hour, "	5,552.	5,509 5
Total water from jacket and 2d receiver, "	20,346.	20,005.
Water from jacket and 2d receiver per hour "	847.7	833.5
Difference between boiler room and engine room records, "	199.	170.
Difference, checking from engine to boiler, "	88.	4.

Pump Data.		
Total revolutions	23,671.	23,664.
Revolutions per minute	16.44	16.43
Piston speed per minute, feet	175.36	175.25
Displacement of plungers per revolution, gals.	424.60	424.52
Total water pumped (plunger displacement), "	10,051,000.	10,046,000.
Plunger leakage, "	3,000.	125.
Net water pumped, "	10,048,000.	10,046,000.
Average discharge gauge reading, ft. el.	400.37	401.37
Average suction gauge reading, " "	106.48	107.37
Average head pumped against, feet	293.89	293.90
Indicator Cards.		
Indicated horse-power	548.71	544.98
Delivered horse-power	517.24	517.01
Friction horse-power	31.47	27.92
Per cent. of friction horse-power to I. H. P.	5.74	5.13
Total number of expansions, from pressures	30.6	32.97
Summary and Results.		
Feed-water per I. H. P. per hour, lbs.	11.648	11.653
Dry steam per I. H. P. per hour, "	11.627	11.632
Feed-water per D. H. P. per hour, "	12.357	12.282
Dry steam per D. H. P. per hour "	12.335	12.258
Duty per 1,000 lbs. feed water (contract), ft. lbs.	160,166,000.	161,240,000.
Duty per 1,000 lbs. dry steam, " "	160,455,000.	161,580,000.
Duty per million British thermal units, " "	143,404,000.	144,365,000.
British thermal units per I. H. P. per minute	216.84	216.51
Mechanical efficiency, per cent	94.26	94.87
Thermodynamic efficiency, " on D. H. P.	18.44	18.59
" " " on I. H. P.	19.56	19.60

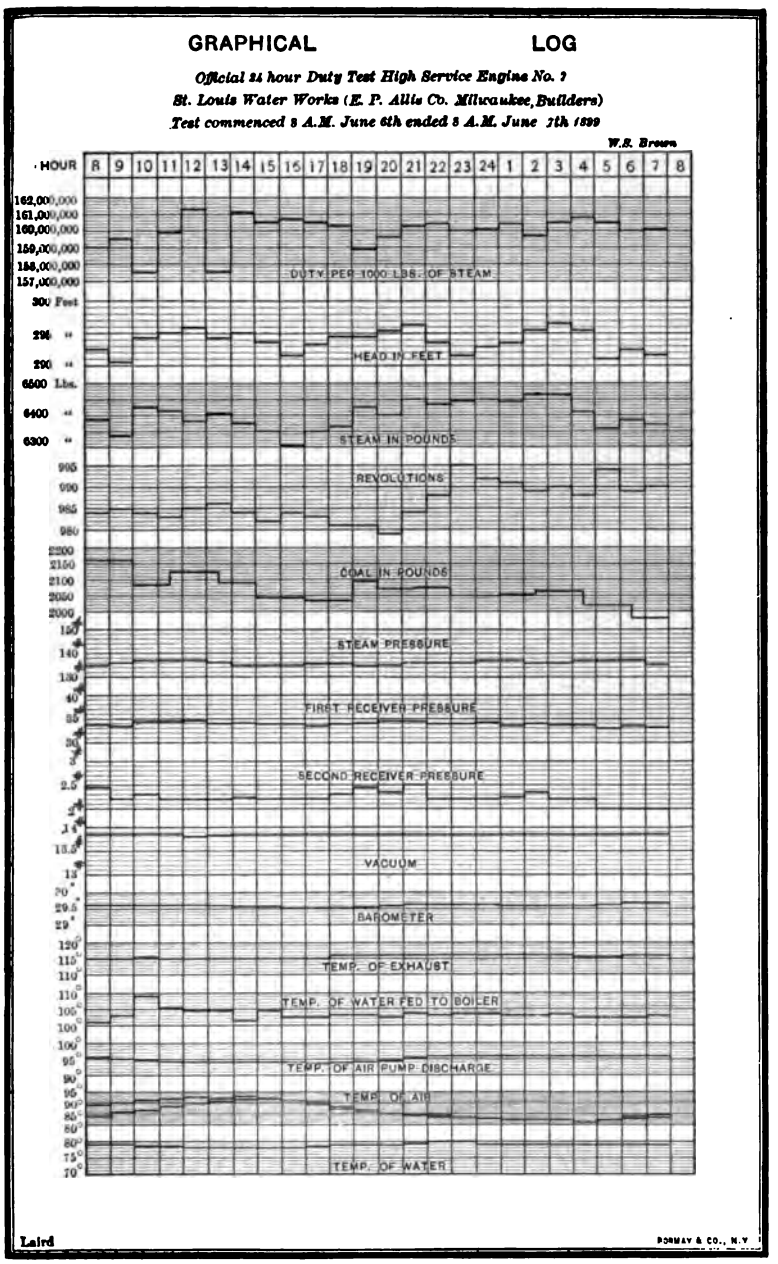

GRAPHICAL LOG
Official 24 hour Duty Test High Service Engine No. 7
St. Louis Water Works (E. P. Allis Co. Milwaukee, Builders)
Test commenced 8 A.M. June 6th ended 8 A.M. June 7th 1899
W.S. Brown
HOUR
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8
DUTY PER 1000 LBS. OF STEAM
HEAD IN FEET
STEAM IN POUNDS
REVOLUTIONS
COAL IN POUNDS
STEAM PRESSURE
FIRST RECEIVER PRESSURE
SECOND RECEIVER PRESSURE
VACUUM
BAROMETER
TEMP. OF EXHAUST
TEMP. OF WATER FED TO BOILER
TEMP. OF AIR PUMP DISCHARGE
TEMP. OF AIR
TEMP. OF WATER
Laird
NORMAY & CO., N.Y.

FIG. 79.

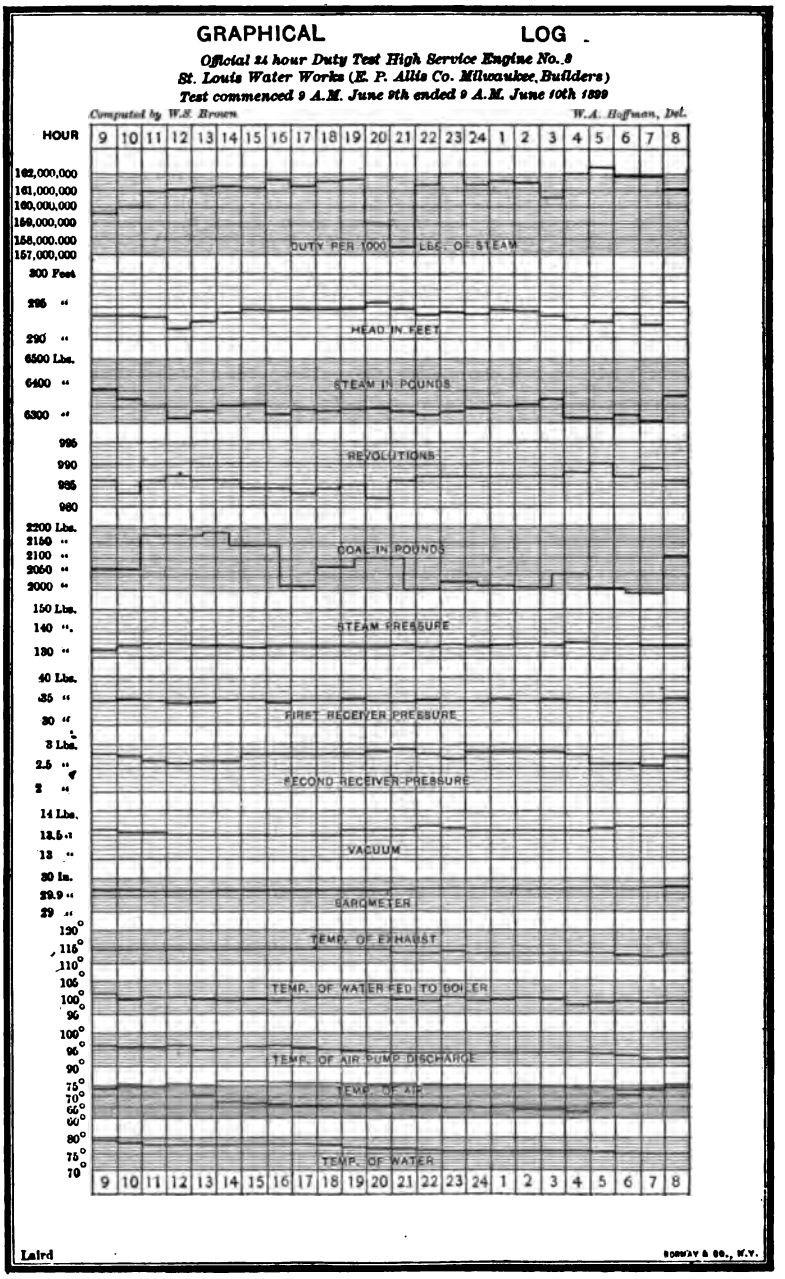

GRAPHICAL LOG
Official 24 hour Duty Test High Service Engine No. 8
St. Louis Water Works (E. P. Allis Co. Milwaukee, Builders)
Test commenced 9 A.M. June 9th ended 9 A.M. June 10th 1899
Computed by W.S. Brown
W.A. Hoffman, Del.
HOUR
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8
162,000,000
161,000,000
160,000,000
159,000,000
158,000,000
157,000,000
DUTY PER 1000 — LBS. OF STEAM
300 Feet
295 "
290 "
HEAD IN FEET
6500 Lbs.
6400 "
6300 "
STEAM IN POUNDS
995
990
985
980
REVOLUTIONS
2200 Lbs.
2150 "
2100 "
2050 "
2000 "
COAL IN POUNDS
150 Lbs.
140 "
130 "
STEAM PRESSURE
40 Lbs.
35 "
30 "
FIRST RECEIVER PRESSURE
3 Lbs.
2.5 "
2 "
SECOND RECEIVER PRESSURE
14 Lbs.
13.5 "
13 "
VACUUM
30 In.
29.9 "
29 "
BAROMETER
120°
115°
110°
105°
100°
95°
TEMP. OF EXHAUST
TEMP. OF WATER FED TO BOILER
100°
95°
90°
TEMP. OF AIR PUMP DISCHARGE
75°
70°
65°
60°
TEMP. OF AIR
80°
75°
70°
TEMP. OF WATER
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8
Laird
BOWLEY & CO., N.Y.

FIG. 66.

DISCUSSION.

Mr. A. M. Mattice.—I would like to ask Mr. Laird about the amount of coal used during the tests. The graphical logs appended to the paper give the coal records, but I am not sure that I have read them rightly. At first I took it for granted that the "coal line" represented the total coal for each hour; the same, for instance, as the "revolutions line" represented the total revolutions for each hour. Figuring the coal on this assumption gave such an absurdly low coal-duty that I concluded that the coal was not plotted on the logs according to the same system as the other data. A further examination led me to believe that each step in the coal line represented the beginning of a fresh car-load. If this were the case, then the coal used on the two tests averaged 29,900 pounds for each 24 hours, which would show a duty of 82,500,000 foot pounds per 100 pounds of coal. The author states that the thermal value of the coal used was only about 11,000 units per pound. Then, supposing that the very best coal, having a value of 15,000 thermal units, had been used, we may assume, by direct proportion, that the above duty would be equivalent to 112,400,000 foot pounds per 100 pounds of best coal. This is so small in proportion to the duty of over 160,000,000 foot pounds per 1,000 pounds of steam, that I would ask the author to say whether my figures as to the coal used are correct, and, if not, to give the correct figures. The fact that one boiler was under banked fires would not account for the low coal-duty.

The low coal-duty can, perhaps, be better judged by examining the evaporation. Assuming my figures to be correct, the water evaporated per pound of coal was only 5.11 pounds at actual temperatures and pressures, or 5.94 pounds from and at 212 degrees Fahr. per pound of coal, or only 6.90 pounds from and at 212 degrees Fahr. per pound of combustile. This is very much less than the thermal value of the coal would call for. In fact it seems almost impossible that any modern boiler could give such a poor result, even after making a liberal allowance for the banked fire.

It is stated that each boiler had 3,000 square feet of heating surface. The evaporation was, on the average, 6,360 pounds per hour, or an equivalent of 7,390 pounds from and at 212 degrees, which is only 2.46 pounds per square foot of heating surface of

one boiler, or only a little over 80 per cent. of the boiler rating on the American Society of Mechanical Engineers' standard; so that the use of the second boiler was quite superfluous. The author states that it would have been difficult to cut out a single boiler, but it would seem as if the removal of a pipe, if necessary, would have been justified, in order to make the test under the best possible conditions. The plan of the boiler house given in the paper would make it appear, however, as if each boiler had its own stop valve. I would therefore ask the author what there was to prevent one boiler alone being used.

A very interesting feature of the test is the very low initial condensation in the high-pressure cylinder. The weight of the jacket water is given in connection with the second receiver drains, but as the latter should be very small in such a well-jacketed and re-heated engine, it may be assumed that the weight given is practically that of the jacket water. Subtracting this from the total steam, and ascertaining the weight of steam present at high-pressure cut-off and from the given pressures, cut-offs, and clearances, it would appear that the steam unaccounted for at high-pressure cut-off was less than 11 per cent. of the total steam through the cylinders. I am sure that those members who are accustomed to finding from 20 per cent. to 23 per cent. initial condensation in high-pressure cylinders of engines of the highest grade will be interested in hearing from the author how this result was accomplished.

I would like to ask also about the jacket steam, whether it was taken from the main steam pipe, or direct from the boilers, and if the pipe was so arranged that it was impossible for any of the jacket water to drain back to the boilers through the supply pipe.

There is one possible source of error in the method of conducting the test which I would point out, viz., the reading of water levels in boilers at the start and stop. At the start, the levels were read at one-half minute intervals for the fifteen minutes *before* the beginning of the test, and at the end they were read at one-half minute intervals for the 15 minutes *after* the end of the test. This gave an opportunity for a very large error, considering the large area of water level in the two boilers. It would have been better to have taken the levels during the 15 minutes *before* the end of the test, to correspond with the beginning.

It would be possible to make a large difference in the amount

of water in the boilers in 15 minutes. To be sure, this was only about 1 per cent. of the length of the test, but unless the water level were very carefully watched during the latter part of the test proper, a large error might be corrected in this short time. A graphical log of feed-water weighings including the hour before and the hour after the test would, however, settle this point.

Prof. D. S. Jacobus.—It is stated in the paper that the indicator springs were calibrated with a special dead-weight apparatus, shown in Fig. 76, by means of which working conditions, in regard to temperature and pressure, were very nearly obtained. The method of manipulating the apparatus is not described, but the printed matter on the figure shows this in a general way.

From the figure it appears that the indicator was subjected to the mean steam pressure which existed during the stroke of the engine, between the times that calibrations were made by taking lines on the test diagram; the idea of so doing being, evidently, to make the temperature more nearly that corresponding to working conditions than is ordinarily the case in testing indicators. This is a refinement not necessary if the proper precautions are employed in other forms of testing apparatus and may, in fact, introduce an error.

The temperature of the spring of an indicator when used on an engine, at pressures above the atmosphere, in ordinary practice, is 212 degrees Fahr. or that of steam at atmospheric pressure. If an indicator is subjected to steam at a constant pressure, the temperature of the spring will soon rise above 212 degrees Fahr. on account of superheating of the steam which leaks by the piston, and this is found to be the case in testing indicators unless the indicator is subjected to the steam but a short time in taking each line of the test diagram. By subjecting the indicator to some constant pressure of steam between the times that the lines are taken, as is done with the apparatus described in this paper, it is probable, therefore, that the steam surrounding the spring would be at all times superheated, and this would introduce an error.

There is an error in the calibrations of indicator springs, made in the ordinary way, which, however, the apparatus described in this paper will eliminate to a great extent. This is the variation of temperature in the parts of an indicator during the time that the spring is being calibrated. If an indicator is continually subjected to a pressure of steam during the time that it is

calibrated and the lines are taken at slowly increasing and slowly decreasing pressures, the temperature of the spring and the parts of the parallel motion above the piston will be greater when the lines of the test diagram are taken for the high pressures than for the low pressures. This is caused, mainly, through the fact that the amount of superheating in the steam which leaks by the piston and surrounds the spring is greater at high than at low pressures. If after taking the highest line on the test diagram an atmospheric line is taken as quickly as possible, it will be found that this line will not agree with the atmospheric line which will be obtained by slowly decreasing the pressure in the way which is ordinarly done in order to obtain the intermediate lines on the test diagram; and the variation between the two atmospheric lines shows the error due to the variation of heat in the parts of the indicator.

When used on an engine the action of the indicator is so rapid that the temperature of the parts of the indicator is practically constant for all pressures, and in our calibrations we should, therefore, strive, as nearly as possible, to obtain the same results. This is accomplished, in a measure, by employing the apparatus shown in Fig. 76 of the paper, but it is not accomplished as well as it is when springs are tested in the way which we finally adopted in our tests. The apparatus used in our tests was described at a meeting of this Society held one year ago. The steam pressure is maintained constant during the time that the lines are taken on the test diagram in the same way as in the apparatus described in this paper, and two three-way cocks are placed between the indicator and the steam chamber so that in case of a slight leakage in either cock the height of the atmospheric line will not be affected.

Having adjusted the pressure of the steam in the testing apparatus to nearly that at which the line is to be taken on the test diagram, steam is admitted several times to the indicator by opening and closing, quickly, one of the three-way cocks which lead to it. A line is then taken at the given pressure, and as quickly as possible after this an atmospheric line is taken. In obtaining the atmospheric line both of the three-way cocks beneath the indicator are shut off for the reason already explained. In taking the line at the given pressure, as well as the atmospheric line, two lines are traced with the indicator; one after pressing the pencil upward and releasing it, and the other

after pressing the pencil downward and releasing it. After pressing the pencil one way or the other and before taking the lines, the indicator is rapped sharply with a small wooden stick in order to reduce the friction. If the indicator is in correct adjustment the two lines taken at the given pressure should fall one over the other. In employing this method a separate sheet of paper is placed on the indicator for each single determination at a given pressure, and as, ordinarily, five determinations are made, twenty-five cards will be required for testing a single spring.

The advantage of using a separate card for each calibration at a given pressure instead of obtaining lines for all the pressures on the same diagram is that the temperature of the parts of the indicator will be more nearly the same at the times that a line at the given pressure and the atmospheric line are taken, than would be the case should the ordinary method be employed. As has already been stated, an atmospheric line obtained as quickly as possible after obtaining a line at the given pressure will, in most cases, be slightly higher than an atmospheric line obtained in the ordinary test of an indicator. In our first tests we desired to follow the usual plan in testing, and being aware of the above discrepancy we heated the indicator to such an extent before taking the first atmospheric line that the discrepancy disappeared. As it was appreciated, however, that the method just described placed the indicator more nearly in the working conditions, and as it was found to be more reliable in the hands of an inexperienced person than the first method, it was finally adopted in all our tests.

In the apparatus shown in Mr. Laird's paper the plug on which the dead weight is placed and which is used as a standard of pressure is heated by the steam. This produces an error on account of expansion, amounting to about 0.3 pounds at 80 pounds steam pressure. In our device the plug is kept cool to eliminate this error, as may be seen by examining the figure which accompanies my paper already referred to.*

Mr. John A. Laird.†—It was not intended to bring the duty on a coal basis into this paper; first, because the contract only required the duty per 1,000 pounds of steam, and no precaution

---

* See *Transactions*, vol. xx., p. 407.

† Author's closure, under the Rules.

was taken to make the boiler test a feature; second, because it is plainly unfair to compare an engine running on poor coal with one running on the best coal, unless, as Mr. Mattice has done in his discussion, we adopt some method of reducing both to a perfect coal.

For the information of the members I am pleased to give the following additional facts from records of the tests:

	No. 7.		No. 8.
Total water fed to boilers and evaporated.	153,398		152,402
Total coal burned	27,197		29,084
Actual evaporation	5.64		5.24
Average actual evaporation on engine tests		5.44	
Boiler efficiency on engine tests	52.63%		56.43%
Average boiler efficiency on engine tests		54.53%	
Efficiency obtained on official boiler tests.		72.6%	
Average evaporation on engine tests if boilers had been run up to official test conditions		7.25	
Duty per 1,000 lbs. feed water	160,166,000		161,240,000
Average duty per 1,000 lbs. feed water		160,703,000	
Average actual duty per 100 lbs. coal (11,000 B.T.U.)		87,422,000	
Average duty per 100 lbs. coal (11,000 B.T.U.) if boiler had been run under official boiler test conditions		116,509,000	
Duty per 100 lbs. of very best coal (15,000 B.T.U.), as per Mr. A. M. Mattice's figures		158,876,000	

The low actual coal duty can be accounted for by two facts: first, that the boilers were not run under the best conditions; second, that the coal was very low grade, costing $1.18½ per ton delivered in the house. The actual cost of coal for pumping 1,000,000 gallons one foot high on these tests is .565 cents. In the same station, burning the same grade of coal, the average cost of pumping 1,000,000 gallons one foot high for three months (including coal used for running machine shop engine) was only .55 cents. This proves conclusively that the station duty per 100 pounds of coal is higher than that shown on engine tests, and that the low coal duty obtained on same tests was due to the inefficient conditions under which it was necessary to operate the boilers.

For practical reasons connected with the operation of the pumping station, which need not be discussed here, the second boiler could not be cut out.

In my opinion the low initial high-pressure-cylinder condensation shown is due to the fact that the range in temperature in high-pressure cylinder is only 86.7 degrees Fahr., and that the steam entering the cylinder was practically dry, showing less than .2 per cent. of entrainment.

The jacket steam was taken out of the main steam pipe between the separator and throttle valve and could not possibly drain back to the boilers.

In relation to the possible source of error due to the method of determining water level in the boilers, I would call attention to the fact that no important error is possible unless the fifteen-minute readings show that the level was changing by an appreciable amount during that time. That the water level was very steady is shown by the fact that the maximum amount by which any reading differs from the corresponding average of the fifteen-minute readings is .13 of an inch. Since one inch difference in water level is equivalent to about 1,280 pounds of water for the two boilers, it is evident that the maximum possible error from this source must be 167 pounds, or less than .11 of 1 per cent. of the total water weighed.

In answer to the discussion by Professor Jacobus, I will say that there is no doubt but that the springs are heated above 212 degrees Fahr. by the superheated steam during calibration, which is exactly as was intended. I believe with him that the temperature of a spring does not change perceptibly during the taking of a card, but hold that it is something more than 212 degrees on a high-pressure card. Granting that the above is true, I also hold that the spring should be calibrated at as nearly as possible its temperature during use on the cylinder. This we have attempted to attain, by keeping, during the manipulation of the apparatus, a pressure on the indicator piston equal to the mean effective pressure in the cylinder during the taking of the card.

The apparatus which Professor Jacobus describes seems to calibrate the springs at different temperatures for each pressure line taken. He says, "Having adjusted the pressure to nearly that at which the line is to be taken on the test diagram, steam is admitted several times to the indicator," etc. Then he quickly takes the atmospheric line. Therefore every pressure line and its corresponding atmospheric line is taken with the spring at a different temperature. In the apparatus described in the paper,

all of the pressure lines and the atmospheric line are taken with the spring at the same temperature, which we make as nearly as possible the temperature of the spring when the original card was taken.

I will also mention that the ordinary precautions of tapping the indicator with a stick, etc., were taken.

The plug on which the dead weight rests does not come in contact with the steam, but works in oil. The whole apparatus is heated up by the steam, and the plug, which was made in the Water Department shop, was figured to be exactly one-half inch in area when at a temperature of 300 degrees Fahr., which is about the mean temperature at which it is used.

No. 841.*

STRENGTH OF STEEL BALLS.

BY J. F. W. HARRIS, TERRE HAUTE, IND.
(Member of the Society.)

RELIABLE data of the actual breaking strength of steel balls not being obtainable, the following tests were made at the Rose Polytechnic Institute preliminary to the design of some ball-bearings for experimental purposes. The balls were obtained in every case directly from the manufacturers, who are designated in the tests by the letters *A* to *F*.

The first experiments in crushing were made with the ball between two flat plates of a high-grade tool steel, which had been hardened in brine. These proved unsatisfactory, the ball embedding itself to a considerable depth. After trying several high-grade steel plates of different brands with no better success, the method shown in Fig. 80 was tried, in which the hardness of the balls was used to obtain a mutually unyielding surface. This apparatus consists of a steel cylinder, bored to two diameters, with a square shoulder nearly midway of its height. Resting upon this shoulder is a thin steel plate, having a hole bored concentric with the cylinder, and whose diameter is one one-hundredth of an inch larger than that of the ball being tested. This plate serves as a guide for the central ball, retaining it in the axial line. Fitting snugly into the bottom of the cylinder is a hardened steel plug, having a conical recess in the centre of its upper surface to retain the bottom ball. In the upper end of the cylinder is a similar plug, fitting loosely, to allow its vertical movement under pressure without friction.

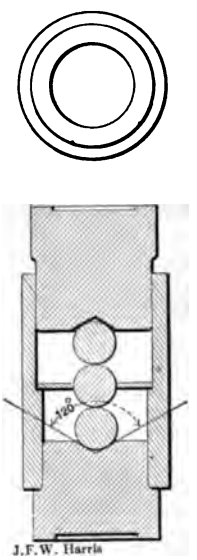


FIG. 80.

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

After adjusting the balls as shown in Fig. 80, this apparatus was placed between the heads of a 100,000-pound Riehle Testing Machine.

While making these tests of ball on ball, the search was continued for a steel which would harden sufficiently to be used as ball races without injurious grooving under ordinary pressures. Several grades of various brands of tool steel, hardened in brine, were tried, their comparative hardness being ascertained by meas-

FIG. 81.

uring the depression made by a quarter-inch ball under a load of 4,000 pounds. These tests resulted in the selection of a steel known to the trade as crucible tool or file steel, and a special steel made by the Carpenter Steel Company, used by them in the manufacture of projectiles. In the second method of testing, all balls up to and including one-half inch in diameter were tested between two plates of Carpenter steel of thirteen-sixteenths inch diameter and one inch in length. The indentations made were almost imperceptible, and were removed by grinding after each series of tests. The larger balls were tested between plates of cru-

cible tool steel two inches square and seven-eighths inch thick, on which but slight indentations were produced.

The results obtained by both methods of testing are shown in the

FIG. 82.

table of "Breaking Loads" on following page, in which the various tests are arranged in order of magnitude for better comparison, the numbers in the second column not having reference to order

FIG. 83.

BREAKING LOADS.

Diameter of Ball.	No. of Ball.	Ball on Ball. A.	B.	C.	D.	E.	F.	Between Flat Plates. A_1.	B_1.	C_1.	D_1.	E_1.	F_1.
½ in.	1	800	760	1,360	940	870	1,020	1,600	*700	1,800	1,250	1,350	*10
	2	1,530	1,070	1,540	1,010	1,060	1,050	1,950	1,200	2,200	1,200	1,500	1,470
	3	2,240	1,150	2,120	1,680	1,210	1,240	3,800	2,150	2,300	1,430	1,600	1,600
	4	.....	.....	.....	.....	.....	1,620	.....	2,200	.....	.....	.....	2,000
Average..	.....	1,523	993	1,673	1,210	1,046	1,232	2,450	1,850	2,100	1,313	1,483	1,690
$\frac{5}{16}$ in.	5	2,360	2,000	2,200	1,250	1,640	2,160	3,530	2,200	2,600	1,800	3,700	3,600
	6	2,880	2,000	2,600	1,260	2,500	3,040	3,980	3,500	2,900	2,000	4,400	3,600
	7	2,900	2,230	2,780	1,480	3,180	3,150	4,000	4,050	3,400	2,200	4,700	4,000
	8	.....	2,580	.....	.....	.....	.....	.....	5,600	.....	2,900	4,800	4,350
Average..	.....	2,713	2,202	2,526	1,330	2,440	2,783	3,836	3,837	2,966	2,225	4,400	3,887
⅜ in.	9	3,860	3,690	3,770	2,600	4,200	4,320	6,700	4,600	4,900	5,400	5,600	6,300
	10	3,900	3,750	3,800	3,340	4,440	4,450	8,720	5,150	5,400	5,800	6,000	6,950
	11	4,430	4,000	5,020	4,000	5,330	4,800	10,580	6,200	6,400	6,900	6,850	*7,600
	12	.....	5,330	.....	.....	.....	.....	.....	6,800	.....	.....	6,900	8,200
Average..	.....	4,063	4,162	4,196	3,313	4,656	4,526	8,666	5,687	5,566	6,033	6,337	7,150
$\frac{7}{16}$ in.	13	*3,080	5,200	4,700	4,600	7,400	5,640	8,480	6,000	9,300	7,000	8,500	*5,500
	14	5,380	5,210	5,100	6,200	7,530	7,730	8,600	6,750	9,600	7,950	9,200	6,300
	15	6,840	6,400	7,000	6,250	7,975	8,100	9,900	7,400	13,600	8,250	9,300	7,200
	16	.....	7,000	.....	.....	.....	.....	.....	7,400	.....	.....	10,100	*7,950
	17	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	13,600
	18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	13,700
Average..	.....	6,110	5,960	5,600	5,683	7,635	7,156	8,993	6,887	10,833	7,733	9,275	10,200
½ in.	19	7,050	5,850	8,400	6,700	6,200	11,800	10,700	10,800	10,500	8,700	9,700	9,800
	20	7,930	5,850	8,480	7,580	6,600	13,040	16,120	13,070	10,600	11,000	10,100	11,400
	21	8,550	5,900	9,220	7,640	8,000	15,090	18,000	14,250	10,650	11,800	12,000	13,000
	22	.....	7,200	.....	7,290	.....	.....	.....	18,050	.....	.....	19,400	19,150
Average..	.....	7,843	6,200	8,703	11,200	6,933	13,310	14,940	14,042	10,583	10,500	12,800	13,337
½ in.	23	18,300	.....	17,450	11,840	10,180	.....	37,000	.....	19,950	12,600	10,400	
	24	21,600	.....	17,850	12,000	10,900	.....	41,450	.....	20,600	15,300	12,900	
	25	23,000	.....	18,400	11,680	12,740	.....	46,860	.....	22,100	16,600	15,600	
Average..	.....	20,966	.....	17,900	.....	11,273	.....	41,770	.....	20,883	11,833	12,966	
⅝ in.	26	*8,800	.....	.....	.....	11,800	.....	35,900	.....	.....	.....	10,500	
	27	17,750	.....	.....	.....	13,040	.....	36,500	.....	.....	.....	20,000	
	28	26,000	.....	.....	.....	16,100	.....	44,200	.....	.....	.....	21,900	
	29	26,800	.....	.....	.....	.....	.....	.....	.....	.....	.....	22,100	
Average..	.....	23,516	.....	.....	.....	13,646	.....	38,866	.....	.....	.....	21,125	
1 in.	30	56,400	.....	.....	.....	.....	.....	88,700					
	31	58,600	.....	.....	.....	.....	.....	92,600					
	32	62,100	.....	.....	.....	.....	.....	.....					
Average..	.....	59,033	.....	.....	.....	.....	.....	90,650					

*Visible defect (not included in averages).

of test. The wide variations as shown therein arise principally from the difference in temper, which varied from brittle hard

FIG. 84.

to that which could be filed with a Stubbs smooth file. The softest balls required the greatest pressure, and flattened until they finally split. Of this character are C_1 15, A 25, B_1 4, F_1 15,

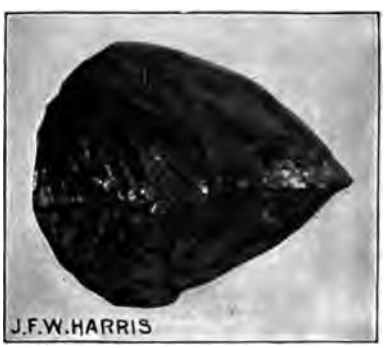


FIG. 85.

FIG. 86.

E_1 22, and F 15. The larger number of medium temper split in two pieces, as shown in Fig. 81; the hardest broke up into

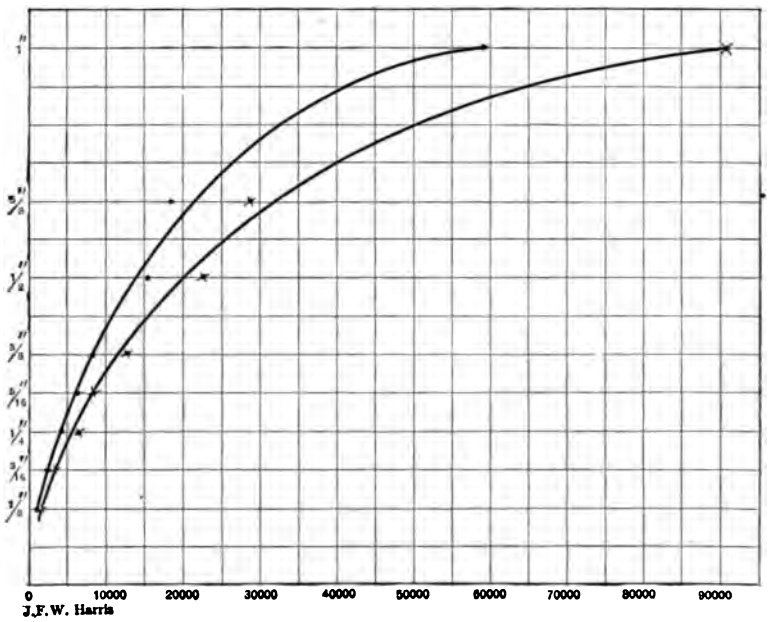


FIG. 87.

a number of pieces, as shown in Fig. 82. The extremes in the appearance of surface, due to hardening, are shown in Figs. 83 and 84, the latter being particularly fine and satiny. The

FIG. 88.

discolorations apparent on the edge of *A* 24 are caused by oil marks.

In testing ball on ball, the centre ball was broken in about eighty per cent. of the cases, the break occurring by the formation

FIG. 89.

FIG. 90.

and forcing of a nearly conical wedge into the ball, the base of the cone being approximately circular. Fig. 85 and Fig. 86 give two different views of the wedge taken from *A* 32. The angle of

FIG. 91.

this wedge was about sixty degrees. When crushing between flat plates this wedge was formed in but very few cases, the balls generally breaking up into a number of pieces, the angle of the wedge in this case being about seventy-five degrees. Of the de-

fects found in the balls other than those of temper, there are four cases of hollow centre, A 13, F_1 13, F_1 16, and B_2 4; and a few cases of fire crack, as A 26, B_1 1, F_1 1, and F_1 11.

The points in the curves in Fig. 87 are the averages taken from the entire series of tests of each size of ball, the upper curve be-

FIG. 92.

ing from the tests of ball on ball, and the lower curve from those between flat plates.

Some experiments to determine the effect of the difference of area in contact on the breaking strength are being made, a few of which are given in the following table:

		1	2	3	4	5	6	7	8		9	10	11	12
B_2 Upper ball.....	$\frac{5}{16}$''	6,700			7,000					1''	6,400	4,950	4,000	
B_2 Centre ball.....	2''		5,400	6,300			6,000		5,500	2''				
B_2 Lower ball.....	$\frac{5}{16}$''					4,000		5,650		1''				5,780

DISCUSSION.

Mr. Gus. C. Henning.—I desire to call attention to the first four lines of this paper, as they explain what the object of making the tests was, viz. : to obtain reliable data of the strength of steel balls, these to be used in the design of roller bearings. It is necessary to point out:

First. That this paper does not supply reliable data for the purposes stated;

Second. That the methods used for the determinations of the data given are not satisfactory; and

Third. That the results given can in no wise be considered as characteristic of the balls tested.

A roller bearing is used primarily to reduce friction, and not resist great pressure or to act as pressure bearings.

Therefore the data about balls necessary to design efficient roller-bearings seem to be the safe loads to which the hardened balls may be subjected without producing change of shape, much less permanent deformation. I am assuming, of course, that the bearing plate is sufficiently resistant, hard, and rigid to retain its shape perfectly under such loads while the balls are travelling over it. If, for instance, a load of one ton were sufficiently effective to change the shape of the ball permanently by even so small an amount as $\frac{1}{1000}$ inch, then this ball would produce excessive friction and wear out in a short time, and the bearing would fill rapidly if such balls were in use.

It does not matter how much pressure would be required to crush the ball, because the above stated elastic failure would take place long before the actual maximum resistance would actually be called into play.

The author shows very clearly that the strength of these balls depends upon the kind of bearing they take, and also upon the hardness of the bearing plate, but he does not determine how much either of these conditions affects the accuracy of his results. His method actually employed is defective in that the superposed balls should have the same hardness, otherwise the bearing surface, or that section actually subjected to pressure, will be determined by the softest ball. The softer a ball, the greater will be its flattening, and hence also bearing surface, with an apparent higher resistance. It must be remembered that these tests are not of square-ended test pieces, but of spheres which

are supposed to touch at two points only when in contact with spheres or planes.

As the author has not made such investigations, I am prepared to say that he has wasted a lot of valuable time in a useless pursuit of knowledge, and the figures may even mislead engineers in their own work. For this reason I propose to give some data on the strength of steel balls which may be of practical value to engineers who desire hereafter to design ball bearings. I have investigated two sizes of balls, ½-inch and ⅝-inch diameter, and made the tests in such a manner that I determined those loads under which they showed permanent change of shape, and also those which crushed them.

It required many hundred micrometric measurements to determine positive change of shape, because a permanent change of $\frac{1}{1000}$ of an inch would mean a very rapid destruction of balls and bearings.

Size of Balls.	Average of	Yield Point in Lbs.	Apparent Crushing Load in Lbs.	Ratio, ⅔.	Maximum Working Load Allowable.	Ratio, ⅔.
⅝ inch.	5 tests.	3,060	51,700	1/17	2,500	1/20
⅝ "	5 "	2,610	36,400	1/14	2,250	1/16
⅝ "	6 "	3,140	50,130	1/16	2,650	1/19
½ "	4 "	1,430	23,400	1/16	1,125	1/19
½ "	6 "	1,220	29,930	1/25	1,025	1/29
½ "	6 "	1,485	21,460	1/14	1,275	1/17

From these results it will be seen that loads which will destroy the practical usefulness of balls in bearings bear no relation to the actual crushing loads.

Moreover, the results of tests of the product of different makers show that balls should always be tested for their elastic properties before making a final design for a bearing.

While the above figures are correct for the balls which I tested, it is not at all certain that the same results would be found from other balls.

I must also point out that these values of loads at "yield-point" are not applicable for practical design, because under these the balls have already been permanently distorted.

Safe loads under which these particular balls would operate safely for a satisfactory period should not exceed the values given in the last column.

Particular attention should be called to the very large ratios between load at yield-point and crushing strength, which is as low as $\frac{1}{3}\frac{1}{5}$ and not above $\frac{1}{1}\frac{1}{4}$, while the ratios between safe loads and crushing strength are still greater, varying between $\frac{1}{3}\frac{1}{5}$ and $\frac{1}{1}\frac{1}{8}$ about.

Now while experience has taught that safe loads in ordinary structures under static stress are as great as $\frac{1}{4}$ or $\frac{1}{5}$ of the ultimate resistances of the material, whether subjected to tensile or crushing tests, my tests given above indicate that in ball-bearings in which $\frac{1}{2}$-inch and $\frac{5}{8}$-inch balls are used the safe loads are only from $\frac{1}{1}\frac{1}{6}$ to $\frac{1}{3}\frac{1}{5}$ of their apparent so-called crushing strength.

With these data, determined as I have stated, it will be easily possible to design safe ball-bearings, which will give satisfactory results during long-continued use.

I wish to emphasize, however, that it will not answer to assume that hardened steal balls are uniform in hardness, or free from defects. I have found very great differences and many defective balls, all due to the hardening and tempering processes used in their manufacture.

While the safe loads above given are applicable when using tested balls, smaller loads should be allowed for untested balls as furnished by all manufacturers.

My experience and that of others has shown that all hardened steel balls should be subjected to a quickly made routine shop-test, which does not require an expert. This test should determine the elastic behavior of the balls. One such device is described in "Martens' Handbook of Testing Materials," p. 328 (John Wiley & Sons, New York).

Prof. William T. Magruder, M.E.—May I inquire just what part of an inch is meant when it is stated that "the ball embedded itself into a flat plate of high-grade tool steel to a considerable depth." Referring to tests made at the Ohio State University, I find that the average indentations made by balls of different makes in flat steel plates were as follows:

$\frac{1}{8}$-inch = .0034 inch, $\frac{3}{1}\frac{}{6}$-inch = .0055 inch, $\frac{1}{4}$-inch = .008 inch, $\frac{5}{1}\frac{}{6}$-inch = .0081 inch.
$\frac{3}{8}$-inch = .006 inch, $\frac{1}{2}$-inch = .018 inch, $\frac{5}{8}$-inch = .024 inch, $\frac{3}{4}$-inch = .030 inch.
$\frac{7}{8}$-inch = .0265 inch, 1-inch = .0267 inch.

These indentations were measured after fracture by a spherometer, and are the averages of from 20 to 40 figures for each size.

Was any difficulty experienced in removing the fractured ball from "the hole .01 inch larger in diameter than the ball," and into whose sides the ball doubtless embedded itself on breaking?

The static strength of balls tested between flat plates is directly proportional to their diameter squared for balls varying from $\frac{1}{8}$ inch to $\frac{3}{4}$ inch. But from tests made on $\frac{7}{8}$-inch and 1-inch balls, it would seem that their strength is only $\frac{2}{3}$ as great in proportion to their diameter squared as are the smaller balls. For $\frac{1}{8}$-inch to $\frac{3}{4}$-inch balls tested between flat surfaces, the average breaking strength of 10 or more balls was found to be $F_{av} = 120{,}000d^2$ pounds, and the minimum strength was $F_{min} = 98{,}000d^2$ pounds. While for $\frac{7}{8}$-inch balls, $F_{av} = 85{,}000d^2$ pounds, and $F_{min} = 67{,}000d^2$ pounds; and for 1-inch balls, $F_{av} = 77{,}000d^2$ pounds, and $F_{min} = 58{,}000d^2$ pounds. I am of the opinion, therefore, that if Mr. Harris will make tests of both $\frac{3}{4}$-inch and $\frac{7}{8}$-inch balls, he will change the curves of Fig. 87 to curves similar to stress-strain diagrams of some steels, being straight lines up to $\frac{3}{4}$-inch, and then turning to a more horizontal direction.

From both Mr. Harris's tests and my own, I am of the opinion that there is a degree of hardness for the races of ball bearings at which for the desired wear there will be the greatest strength. That there is, in other words, the possibility of getting the races of ball bearings too hard for the maximum strength, wear, and preservation of the balls and bearings.

Mr. Chas. W. Thomas.—I fail to see how Mr. Harris has assisted us in the design of a ball bearing. The experiments may be very fine from the standpoint of a laboratory experiment, but what is wanted to enable one to design a ball bearing I think has been lost sight of. This form of bearing has greatly reduced friction. The ideal is one in which the balls are all perfect spheres; if they change their shape either on account of wear or pressure, they fail to perform their function and must be replaced. I should think, then, that the experiments should have been so arranged as to determine what pressure the bearings would stand without the balls changing their form materially. The actual breaking strength can never be reached in any of the bearings, so that the safe limit will be passed long before we reach the breaking strength. If experiments could be tried whereby the friction and pressure could be accurately measured, we would then have some reliable data upon which to base our calculation in the design of this form of bearing.

Mr. Oberlin Smith.—The remarks of Mr. Henning are very interesting and practical; and that jumping test is a peculiarly pretty notion. There seems to be a great ignorance regarding the qualities of the balls and rollers which are being used so much in bearings, and are going I think to be used a good deal more than now. It generally strikes one with surprise to see what a very heavy crushing strength a ball or a roller has, when we consider that theoretically there is only a point or a line of bearing, or practically but a small surface due to elastic flattening. Some years ago I had some tests made at Watertown on a number of hard-steel rollers 3 to 6 inches in diameter and 1 to 2 inches long. I was surprised at the enormous pressures they withstood. Assuming that they flattened enough to give one-eighth of an inch width of bearing, the pressure ran up over 400,000 pounds to the square inch. Of course, the explanation is obvious; it is simply that the part that resists the crushing is penned up—so to speak. Although steel is perfectly crushable at some certain pressure, it is like any other fluid, if we may so term it. When we confine it in a jacket, it is incompressible, or practically so. Here we have in this dark shaded part (referring to a sketch) a portion of the metal which is penned up in the jacket that surrounds it—this jacket consisting of the outer parts which are not compressed. We may assume, with a given flattened surface touching, that the bigger the ball the more pressure to a square inch we can get on that given area.

I did not get up to tell anything I know, but to tell what I don't know and to call out inquiries. I want some of our mathematical friends, if they haven't already done it, to formulate some laws which will govern this subject. Knowing the elastic strength, the elastic limit, and the crushing strength of the hardened metal, we want to know just how much a ball made of it will flatten under various given pressures, elastically. We should know the diametral deformation in both directions and what area of contact surface is obtained when pressed respectively against other balls and against flat surfaces. We should also know what is a safe load to put upon it. These data should be worked out not only for balls but also for rollers. Obviously, long rollers will be stronger in proportion to their length than short ones, because the latter have relatively more unjacketed metal at the ends which is liable to crush outwards. These tables in the paper are very interesting to tell the actual strength, but, as Mr.

Henning says, we want to know a good deal more than that. It is shown that the strength of a ball (looking at this table) is enormously greater than is due to the actual area of surface in contact. If the ball was a cylinder standing on end, it would stand an amount only due to its cross-sectional area; but this "jacketed" metal is entirely different, for we see that the one-inch ball (for instance) has an average of almost 60,000 pounds in the first part of the table and some 90,000 in the latter part. This ball would have about three-quarters of a square inch cross-section at its great circle, and therefore stood some 120,000 pounds per inch, or about what unhardened steel would stand if it was a cylinder. Hardened steel would stand probably twice as much—according to its quality and hardness.

Another thing that is interesting in this table is the extreme variation of the balls in the same column. I assume these different letters represent different manufacturers. Can anybody enlighten me on that?

Mr. Henning.—Most likely.

Mr. Oberlin Smith.—If you will take the eight-inch ball in column A, the average is 1,500 pounds. The quarter-inch ball, being twice the diameter, would be of four times the cross-section and should bear four times as much. It does not, however, bear three times as much. Take the quarter-inch ball at 4,000 and the half-inch ball at 21,000, we have in the latter more than we would expect. Take the half-inch ball at 20,000 and one-inch ball at about 60,000, and we have again only three times the strength. Some of the columns show worse results than this. So we see at a glance that balls from the same maker, of different diameters, vary very much in their crushing strength. Mr. Henning shakes his head. I would like to have him explain why that isn't so.

Mr. Henning.—Because you cannot compare those figures, as I explained. You cannot use those figures as a basis of comparison.

Mr. Smith.—Why not—in a given column?

Mr. Henning.—Because the balls are of different sizes and the conditions of the tests are totally different. Those figures of crushing strength must not be compared in any case to show the actual strength or utility of the balls.

Mr. Smith.—The utility depends on the elastic strength and the amount of flattening. But leaving this out of the question, as we are going to get at it later, when some of you experiment-

ing and calculating people give us the figures, why should not a half-inch ball stand four times as much as a quarter-inch ball? Why should not a one-inch ball stand four times as much as a half-inch ball?

Mr. Henning.—The conditions under which those tests were made are such that those results obtained are entirely valueless. If you do not provide different conditions of tests, what is the use of making the tests? It is simply work thrown away, and the figures cannot be compared as Mr. Smith would like us to do. I gave figures which can be compared. When you look at the figures that I gave, you will find that they bear some relation to the size of the ball provided the ball is uniform in hardness.

Mr. Smith.—I think that these two tables will give us a rough idea of what balls will stand, but they do not go nearly far enough. I cannot fail to see, however, that these balls were not anywhere near uniform.

Mr. Henning.—I will show you. This does not show the true facts in the case. This is supposed to be the flattened surface. That is not the bearing surface at all. The bearing surface is something else very much larger, because this ball is compressed elastically out *here* and this plate is pressed elastically out *here*, and the total bearing surface is something like *this*. I want to call attention to the fact that I consider the strength of balls about 400,000 pounds per square inch should not be put on record. I would like to say more, but you understand me. There is no such material. If you take this whole area in place of this little crushed area, you will at once get a reasonable practical strength of this steel under that pressure. If you test a small ball like this and then a larger ball, the ratio between this total area and that area is one that depends on the ball and the softness of the metal and the softness of the plate. None of these conditions have been taken into account. Therefore I say that, this not having been done and the actual surface not provided for, what is the use of using the figures for comparison?

Mr. Smith.—I am willing to give just as bad a character to that table as Mr. Henning is—as far as the badness of its balls goes, in the matter of lack of uniformity in the case of a certain manufacturer. It is very irregular all through, but that does not condemn its compiler, who deserves full credit for the trouble he has taken.

Mr. Henning.—But I would not condemn the balls. I would condemn the way the tests were made.

Mr. Smith.—I have not condemned the balls—only their relation to each other. They were not uniform, and the tests show it in any one of those columns.

Mr. C. R. Pratt.—Up to ½ inch in diameter I know of no process by which the ideal ball, both hard and tough, can be commercially produced with absolute uniformity. I have specified and obtained special grades of steel and supervised the hardening of half-inch balls made from it where 75 per cent. of them were too hard to file and too tough to break, but the other 25 per cent. were, to use a crude expression, rotten. Could this 75 per cent. be distinguished and separated from the rotten 25 per cent. the process would be commercial, but I have tried all the methods that have been suggested here this morning, and many more, but the only reliable test that I know of is the one which the old lady gave the matches. Mr. Gantt succeeded in producing a uniformly hard and tough half-inch ball just before he went out of the ball business, and now the only class of ball up to that size on the market is made of a fair grade of tool steel and can be obtained of any degree of hardness with perfect uniformity by various tempering methods, the oil bath being the best and the easiest way, and are all that could be required for all ordinary loads.

It is a singular fact that the Cleveland Machine Screw Company produce a five-eighth-inch ball which is uniformly ideal in hardness, strength, and toughness. I have used and tested thousands of them without finding a single defective ball. They have never produced any other size ball of this rare quality, nor has any other ball-maker to my knowledge. I have heard several ball experts say that a five-eighth-inch diameter tool-steel ball can be more reliably treated than any other size. I believe that this is a fact and would advise the use of this size wherever it is practicable.

Mr. W. F. Mattes.—I would like to ask the gentlemen who have just discussed this question whether they know any case wherein the crushing strength of balls cuts any figure whatever, where we need to know anything more than we know now about the strength of balls. I know of none, unless it should possibly arise in the discussion of projectiles in their impact upon armor plates. It seems to me that the whole question concerning balls

that we need to know is what pressure they can bear without abrasion of their surfaces.

Mr. Henry Souther.—I should be very glad to have such facts ascertained as Mr. Smith brings up, and they would be very useful in starting the design for a bearing. The crushing strength, in my opinion, amounts to very little. It is the abrasive wear. The point to be determined is how much distortion is allowable to give a fair life to the ball in actual use. After these figures are all determined and we are able to get the data necessary, there is another thing in connection with the use of balls which is perhaps of a great deal more importance than the strength of the ball itself, and that is the surfaces between which it is put and the design of the surfaces, or rather the design of the bearing as a whole. There are bearings designed to-day, and quite a large number of them, in which no ball will stand, no matter how light the apparent load is, simply because there is a wedge action brought to bear which the designer does not anticipate at all. Several cases of that kind have been brought to my attention where the people have been driven to distraction and searched the markets of the world practically to get a ball which would stand the service. The ball was not the cause of the difficulty; it was the bearing itself. A very slight change in the shape of it did away with all difficulty, and any ball would do.

Mr. Oberlin Smith.—The discussion rather leads to the idea that we must be very practical and find out what these balls will actually stand, the mathematics and the theory of the question being of no account. I say, take experiment and theory both, as in all good engineering. Let us find out first the laws which govern the crushing of balls, what they ought to stand with a given crushing strength and a given elastic strength per square inch of the given material. Then let us know what they really do stand on an average. Then, for practical work, let us allow a big safety factor, for two reasons: one to allow for bad balls, and the other to allow for wear. This may be a very big factor, ten, twenty, or any other amount, much greater probably than in many other constructions. But let us know first what a given steel ought to stand in the form of a ball and in the form of a roller. Then with a good safety factor we should get good results.

*Mr. J. F. W. Harris.**—As stated in the first paragraph, these

* Author's closure, under the Rules.

tests preceded some ball-bearing experiments. These were, however, not sufficiently advanced to present at this meeting. The intent of this paper was that it should serve only the purpose that its title indicates.

As Mr. Henning condemns the methods employed in testing the balls, by reason of the undetermined bearing they take and the unknown hardness of the bearing plate, it is to be inferred from his positive statements in the superiority of results substituted, that his methods, though not given, were correct, for he advances the results obtained, to be taken as "of practical value to engineers who desire hereafter to design ball-bearings." He also states, "With these data determined as I have stated it will be easily possible to design safe ball-bearings which will give satisfactory results during long-continued use." When we compare the table of breaking loads under the heading of "Between Flat Plates" in my results with those in his table of "Crushing Loads," it would seem to indicate that his tests were made by this same condemned method, and therefore must be as valueless. I would invite comparison of his column of "Maximum Working Load Allowable" with the breaking loads of the same size balls in columns D_1 and E_1.

From all data so far obtained, the given "maximum working load allowable" per ball is higher than the bearing plates themselves will stand without injurious grooving, and I trust that the figures so given will not "mislead engineers in their own work."

In reply to Professor Magruder I would say that no difficulty was experienced with the apparatus in testing ball on ball, and that the guide plates were not injured in any of the tests.

No. 842.*

IMPACT.

BY W. J. KEEP, DETROIT, MICH.

(Member of Committee on Methods of Testing, Etc.)

THE object of this paper is to show the influence of impact upon test bars of various sizes.

The Test Bars are 1 inch by 1 inch, 1 inch by ½ inch, ½ inch by 1 inch, and ½ inch by ½ inch in section. One set is 24 inches long and another set is 12 inches. The bars are of tool steel having a uniform spring temper produced in a gas muffle by the Detroit Edge Tool works. Each bar was then ground to the exact standard size on a surface grinder.

The Recording Apparatus (Fig. 93) holds the ends of the bars

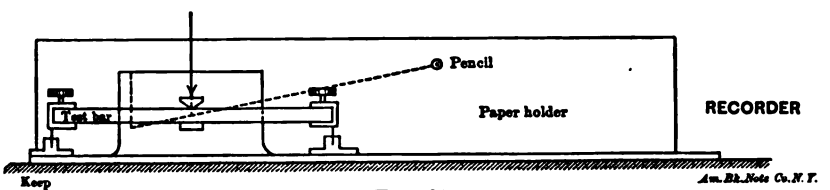


FIG. 93.

in clamps which rest on bearings exactly 24 inches or 12 inches apart, made of spring steel, so as to follow the test bar as it bends. The impulse is received by a cage clamped to the centre of the bar, and the motion is multiplied five times by an arm which carries a pencil at its end, which makes an autographic diagram of the movement of the centre of the test bar.

The rear end of this recording arm is hung by a piece of ½-inch spring steel. At one-fifth of its length from this end the cage, which is clamped to the centre of the test bar, is suspended by two ⅜-inch pieces of spring steel, one on either side of the arm. Between this and the pencil end is a parallel motion which causes the pencil to travel in a straight line, at right angles to the motion of a flat piece of paper which slides under the pencil point.

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

During an impulse all of the steel suspension pieces of the recorder are in tension, and as there is no lost motion the pencil records the motion of the centre of the test bar.

This recorder fits three testing machines, of which the following is a sufficient description :

Dead Load (Fig. 94).—A single lever machine with a 100-pound

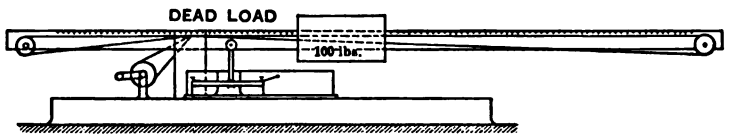


FIG. 94.

weight rolling out on the beam, the load being applied to the test bar through a post which rests in the cage of the recorder, which is clamped to the centre of the test bar.

The crank by which the weight is moved along the beam also moves the record paper.

Impact Testing Machine (Fig. 95), *with its hammer swinging*

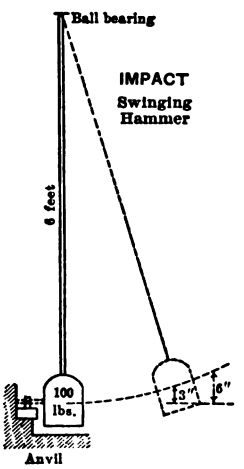


FIG. 95.

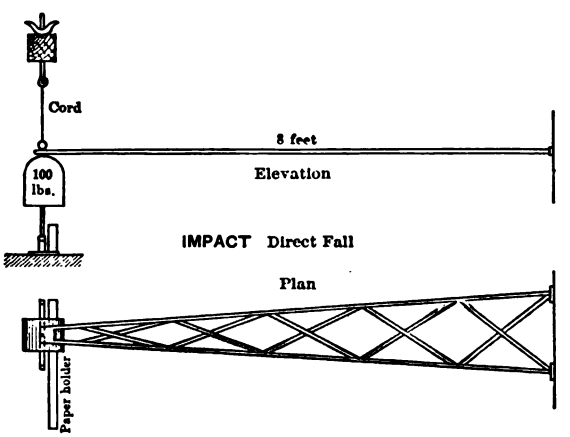


FIG. 96.

on a wooden vertical arm 6 feet long. The weight of the hammer can be varied between 25 and 100 pounds.

A graduated arc, having holes at distance sequal to $\frac{1}{8}$ inch increase of drop, with a trip, allows a drop from $\frac{1}{8}$ inch to 6 inches. The anvil against which the recorder rests weighs 1,000 pounds,

and this rested against a 20-inch brick wall when the tests were made.

Direct Impact Drop Test Machine (Fig. 96), with the same hammers hung on a horizontal wooden arm 8 feet long, which allows the hammer to drop practically in a vertical line without guides.

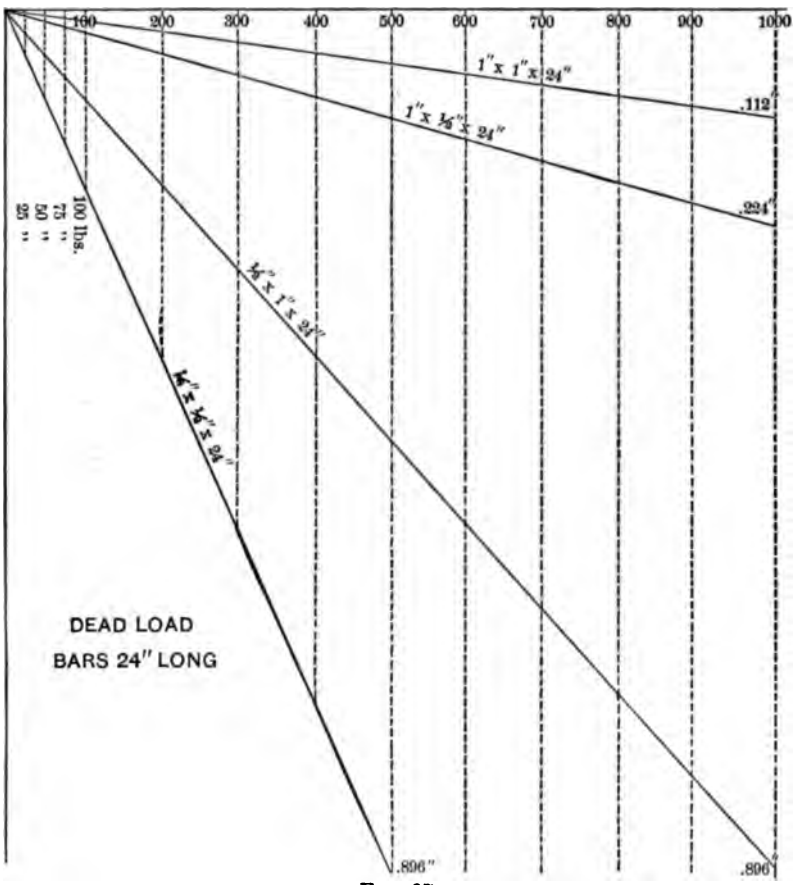


FIG. 97.

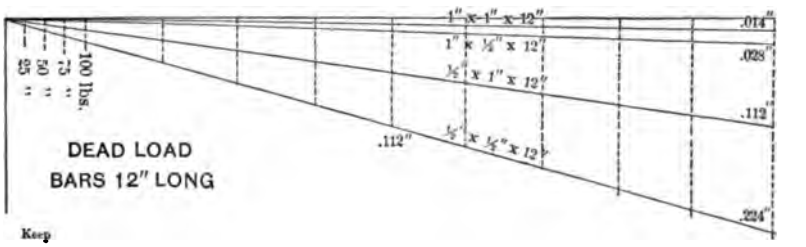


FIG. 98.

The hammer is fastened by a cord to a timber overhead, and is then raised or lowered by a thumb screw until it is exactly the required height above the test bar.

The cord is cut by a tinner's snips to let the hammer drop.

With a swinging hammer the bar receives the impulse in a horizontal direction and the bar bends until the motion of the hammer is stopped. The bar then springs back and throws the hammer away, when it is caught by the hand and clasped to the trip for the drop from the next higher point. The dead weight of the hammer is carried by the vertical arm to which it is attached.

Autographic Records of the motion of the centre of the test bar, if the paper remained stationary, would be a straight line showing the amount of deflection. If the paper was moved slightly after the first blow, the second blow of the hammer would make a record alongside the first, and so on.

To obtain a complete record of each motion of the centre of the test bar, a shaft $\frac{3}{4}$ inch in diameter was made to revolve 1,250 revolutions per minute. The paper holder was connected to this shaft by a cord. Just as the blow was given the shaft was caused to revolve, and the winding of the cord caused the paper to move its whole 24-inch length in half a second. When the paper has moved its whole length, it strikes a stop and the cord breaks. The length of the diagram of a single impulse, and of the vibrations until the bar comes to rest, is from 1 to 4 inches, and the pencil makes this record in from $\frac{1}{48}$ to $\frac{1}{12}$ of a second.

Description of Diagrams.—A large number of series of tests were made, and the actual results were used to construct the diagrams. The curves are of the same size as made by the machines. All vertical distances measure deflection, and should be divided by 5 to give the actual deflection of the test bar.

To do this, *use a scale divided into twentieths, and call the readings hundredths of an inch.*

Dead-load Diagrams (Figs. 97 and 98).—It must be remembered that all of these test bars are perfectly elastic for the loads applied to them, and for this reason deflections are proportioned to loads, and each diagram showing dead-load stress and strain is a straight line. An examination of the diagrams shows that:

Deflection is inversely as the breadth of the test bar.
" " " " cube of the height of the test bar.
" " directly " " " length " "

TABLE I.

	Dead Load.	25 lbs.	50 lbs.	75 lbs.	100 lbs.	200 lbs.	300 lbs.	400 lbs.	500 lbs.
Deflections in inches.	1 in. x 1 in. x 24 in.	.0028	.0056	.0084	.0112	.0224	.0336	.0448	.0560
	1 " x ½ " x 24 "	.0056	.0112	.0168	.0224	.0448	.0672	.0896	.1120
	½ " x 1 " x 24 "	.0224	.0448	.0672	.0896	.1792	.2688	.3584	.4480
	½ " x ½ " x 24 "	.0448	.0896	.1344	.1792	.3584	.5376	.7168	.8960
	1 " x 1 " x 12 "	.0003	.0007	.0011	.0014	.0028	.0042	.0056	.0070
	1 " x ½ " x 12 "	.0007	.0014	.0021	.0028	.0056	.0084	.0112	.0140
	½ " x 1 " x 12 "	.0028	.0056	.0084	.0112	.0224	.0336	.0448	.0560
	½ " x ½ " x 12 "	.0056	.0112	.0168	.0224	.0448	.0672	.0896	.1120

TABLE II.

Size Bars.	Weight of Hammer.	Deflections with SWINGING Hammer. Height of Drop in Inches.						
		0 in.	¼ inch.	1 inch.	1¼ inches.	2 inches.	2¼ inches.	3 in.
1"x1"x24"	25 lbs.	.0	.060	.087	.105	.122	.130	.144
	50 "	.0	.075	.107	.130	.150	.162	.176
	75 "	.0	.088	.126	.152	.175	.193	.210
	100 "	.0	.099	.141	.172	.200	.220	.240
1"x½"x24"	25 "	.0	.077	.110	.139	.158	.175	.194
	50 "	.0	.100	.145	.174	.201	.226	.250
	75 "	.0	.122	.175	.210	.241	.271	.300
	100 "	.0	.141	.200	.241	.280	.314	.347
½"x1"x24"	25 "	.0	.110	.165	.205	.237	.270	.300
	50 "	.0	.168	.242	.300	.350	.400	.435
	75 "	.0	.210	.314	.385	.448	.508	.550
	100 "	.0	.260	.370	.460	.532	.605	.665
½"x½"x24"	25 "	.0	.150	.225	.280	.322	.365	.410
	50 "	.0	.230	.332	.410	.470	.530	.580
	75 "	.0	.295	.425	.525	.600	.670	.732
	100 "	.0	.342	.493	.610	.705	.791	.870
1"x1"x12"	25 "	.0	.035	.048	.057	.069	.078	.084
	50 "	.0	.044	.065	.080	.093	.107	.119
	75 "	.0	.053	.080	.099	.118	.133	.149
	100 "	.0	.062	.093	.115	.138	.155	.174
1"x½"x12"	25 "	.0	.046	.062	.026	.090	.100	.110
	50 "	.0	.058	.084	.100	.118	.133	.147
	75 "	.0	.069	.100	.120	.140	.160	.177
	100 "	.0	.080	.115	.138	.162	.186	.203
½"x1"x12"	25 "	.0	.060	.090	.110	.125	.139	.150
	50 "	.0	.080	.115	.140	.161	.182	.200
	75 "	.0	.100	.120	.175	.200	.223	.246
	100 "	.0	.119	.166	.200	.234	.265	.293
½"x½"x12"	25 "	.0	.070	.100	.126	.148	.155	.181
	50 "	.0	.091	.131	.164	.191	.218	.239
	75 "	.0	.117	.165	.207	.238	.270	.295
	100 "	.0	.140	.197	.241	.280	.315	.345

TABLE III.

Size Test Bars.	Weight of Hammer.	Deflections with DIRECT DROP Hammer. Height of Drop in Inches.						
		0 in.	¼ inch.	1 inch.	1¼ inches.	2 inches.	2½ inches	3 in.
1″x1″x24″	25 lbs.	.005	.065	.092	.119	.130	.145	.150
	50 "	.010	.080	.115	.140	.159	.174	.187
	75 "	.015	.100	.135	.162	.181	.201	.219
	100 "	.020	.116	.160	.187	.209	.230	.248
1″x¼″x24″	25 "	.011	.087	.130	.155	.174	.191	.205
	50 "	.023	.112	.165	.196	.221	.241	.265
	75 "	.034	.134	.191	.229	.262	.289	.316
	100 "	.047	.161	.221	.266	.305	.339	.370
¼″x1″x24″	25 "	.046	.145	.205	.251	.285	.315	.340
	50 "	.084	.230	.317	.376	.420	.454	.483
	75 "	.126	.300	.415	.485	.531	.571	.611
	100 "	.171	.359	.482	.564	.620	.670	.715
¼″x¼″x24″	25 "	.070	.206	.300	.365	.418	.456	.482
	50 "	.141	.332	.453	.525	.578	.618	.652
	75 "	.230	.453	.586	.663	.720	.766	.800
	100 "	.333	.566	.702	.790	.851	.900	.941

Impact Diagrams made with a Swinging Hammer (Figs. 99 to 108).—The regular diagram is made by moving the paper slightly for a base line when the test bar is at rest (see Fig. 124). The hammer is then raised to a catch hung in the hole of the graduated arc for ⅛-inch drop and let drop upon the test bar. The record is a vertical line five times as long as the actual deflection of the centre of the test bar. The paper is then moved a trifle, and the hammer let drop ¼ inch, and so on, each drop being ⅛ inch higher than the next preceding.

Each record is continued above the base line, because when the hammer swings back the centre of the test bar goes past its original position, and the bar vibrates several times before it comes to rest. By drawing a line through the lower ends of the record line we get a curve showing the total deflections for drops from 0 to the highest drop. By connecting the upper ends of the record lines we have a curve showing the vibrations of the test bar. As this record has nothing to do with the deflections, these records will be omitted. Figs. 99 to 102 and 104 to 107 show the deflections for blows from 0 to 3-inch drop on all of the eight test bars, and with hammers weighing 25, 50, 75, and 100 pounds. Figs. 103 and 108 show the

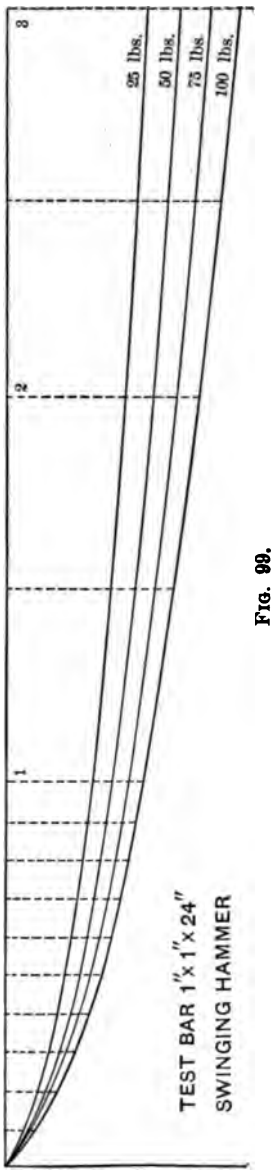


FIG. 99.

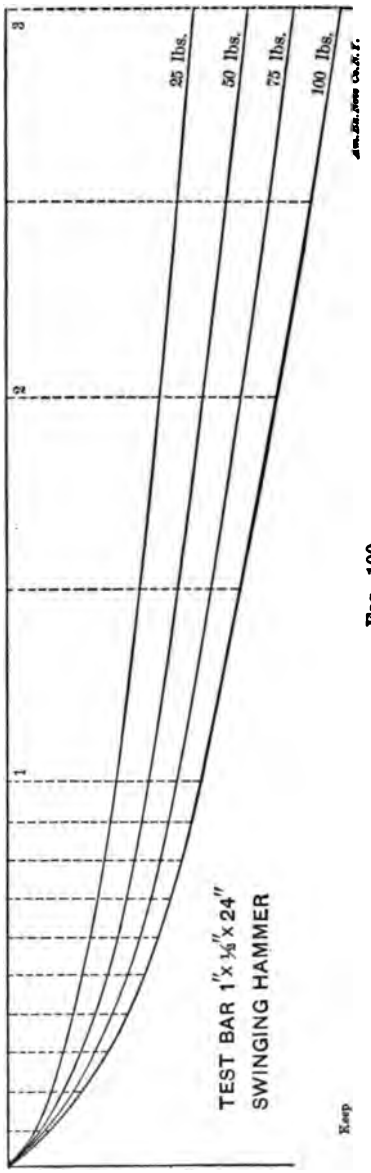


FIG. 100.

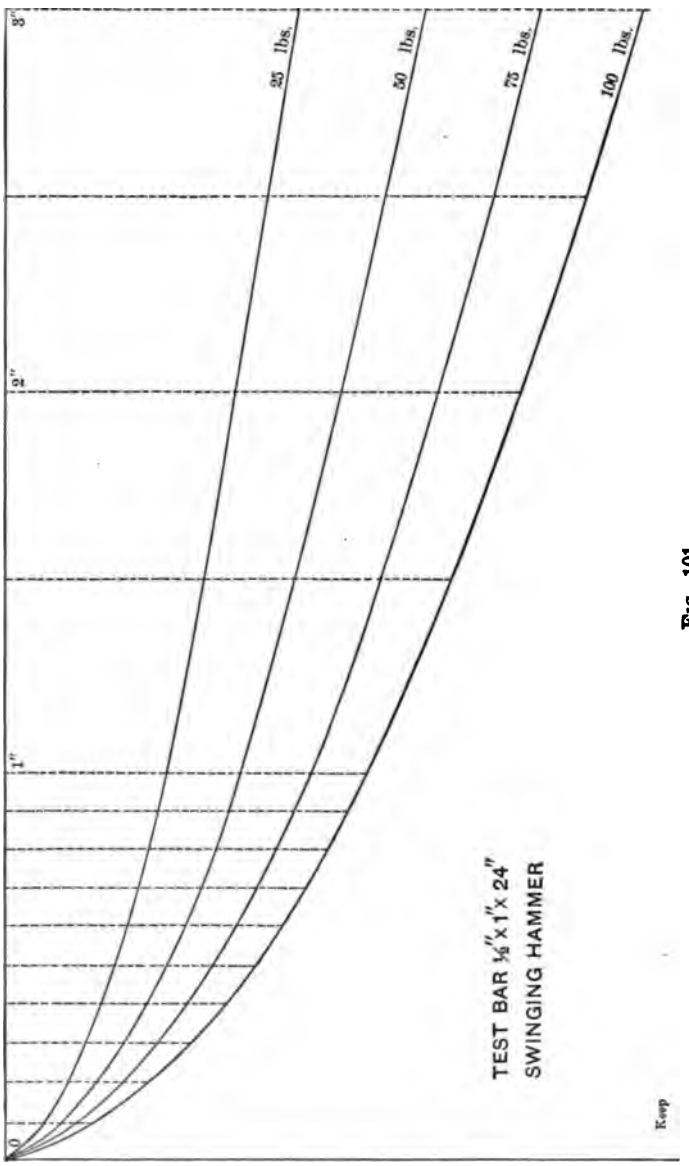

25 lbs.
50 lbs.
75 lbs.
100 lbs.
0
1"
2"
3"
TEST BAR ½"x1"x 24"
SWINGING HAMMER
Keep

FIG. 101.

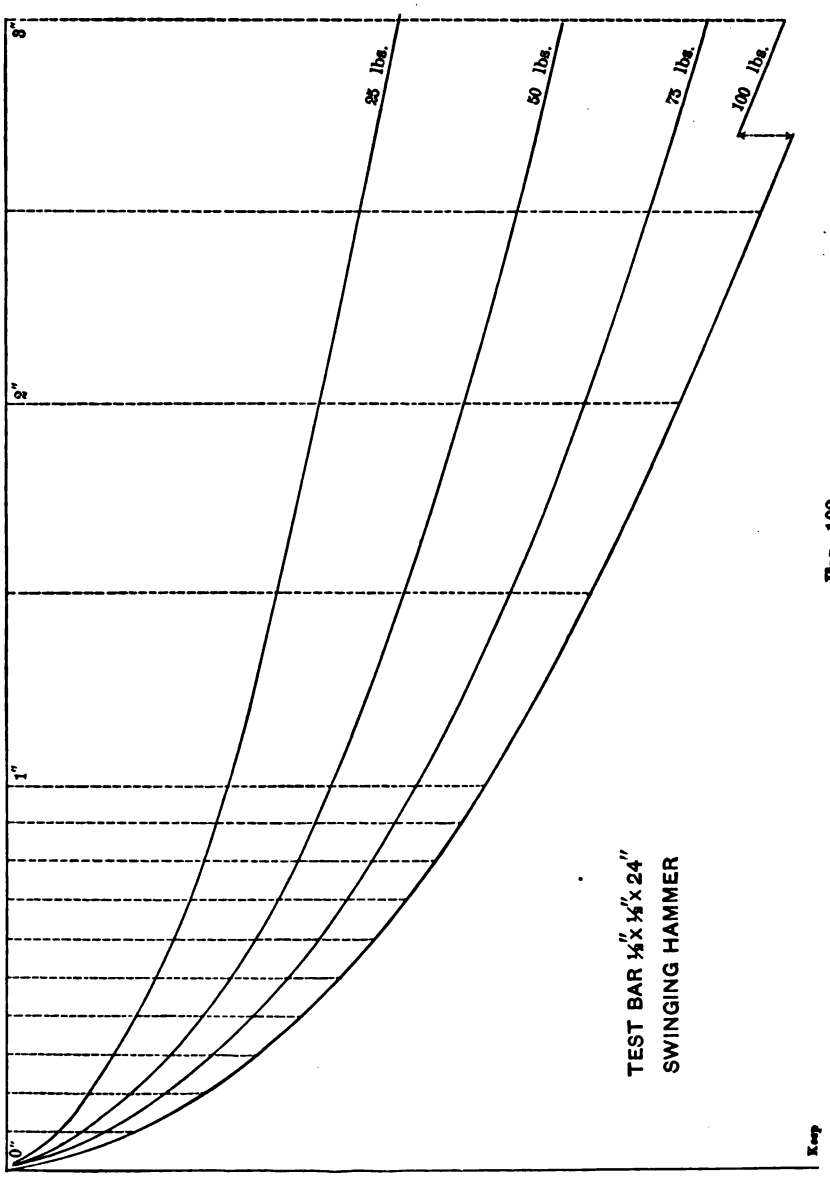

3"
2"
1"
0"
25 lbs.
50 lbs.
75 lbs.
100 lbs.
TEST BAR ½" X ½" X 24"
SWINGING HAMMER
Kgm

FIG. 102.

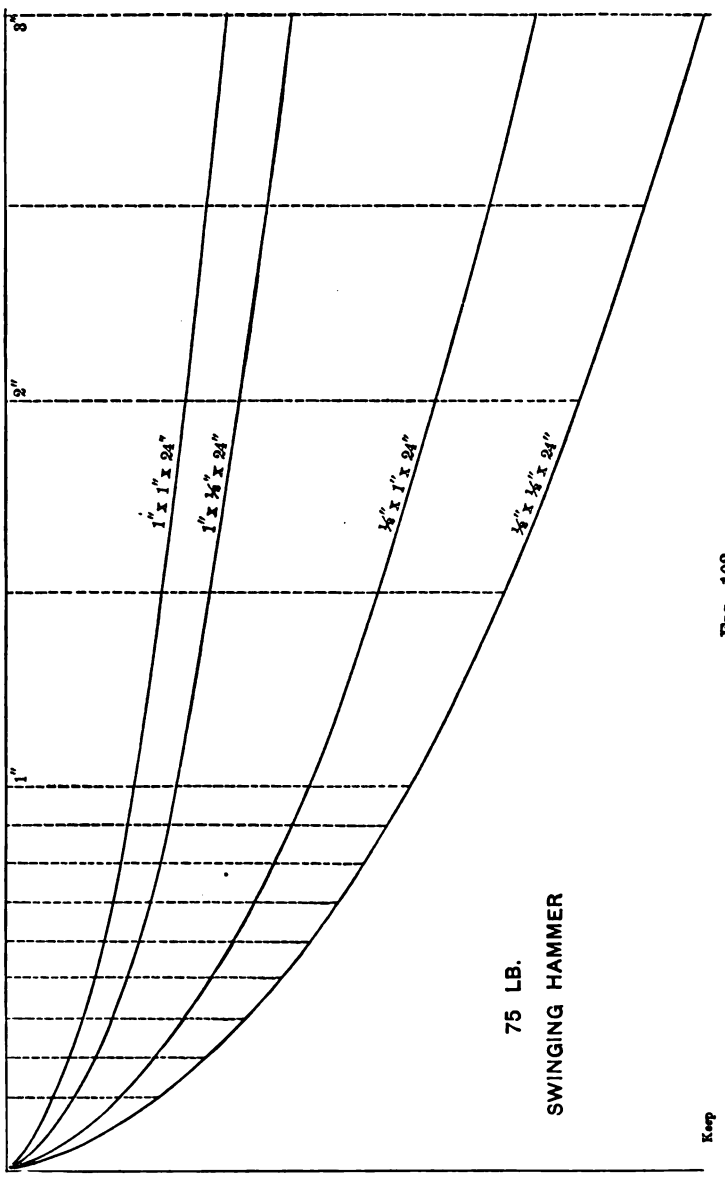


FIG. 108.

FIG. 104.

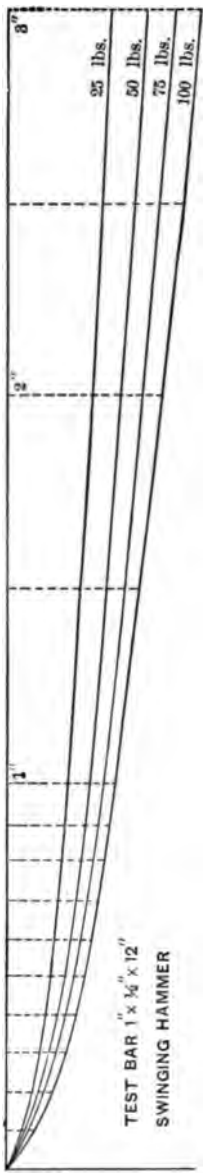


FIG. 105.

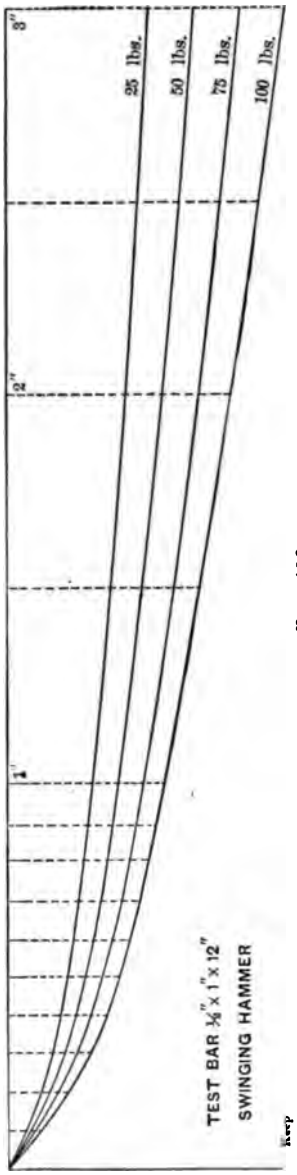


FIG. 106.

deflections with the same falls of a 75-pound hammer on all of the test bars.

Impact Diagrams made with a Hammer having a Direct Drop (Figs. 109 to 113).—All diagrams with the swinging hammer began with 0 deflection for 0 drop.

The diagrams (Figs. 109 to 113) were constructed from actual records of direct drop, with the exception of 0 drop, which in most cases was estimated, as the deflection was too small to measure.

Diagrams of Individual Blows.—The paper moved at the rate of 48 inches per second. The diagrams (Figs. 114 to 119) are reduced to one-third actual size. Figs. 114 and 116 are swinging blows from 25 and 100 pound hammers, both 1 inch drop, on the same test bar. The bar vibrated once and a trifle more with 25 pounds, and twice as many times with 100 pounds. With a swinging hammer the hammer is caught by the hand and allowed to strike the test bar but once. By letting the hammer swing against the bar until it came to rest, the 25-pound hammer made the series of records shown in Fig. 115 and the 100-pound hammer the record of Fig. 117.

Fig. 118 is a diagram from 0 drop of 100-pound hammer.

Fig. 119 is a diagram showing the influence of a single direct 1-inch drop of 25 pounds as compared with the influence of a single 1-inch drop of a 25-pound swinging hammer (Fig. 114).

Diagrams from Test Bars which are not Perfectly Elastic.—Fig. 121 shows a dead-load diagram from a bar of ingot iron $\frac{1}{2}$ inch by $\frac{1}{2}$ inch by 12 inches. When the metal began to flow rapidly the load was removed, and the pencil rested a distance below its original position equal to the set taken by the test bar. When the load was again applied, a new diagram was made which joins the former diagram at the point where the load was released. After a load has been applied to any iron test bar, the bar is perfectly elastic for all loads less than the test load. I therefore call the diagram a spring line, which is made by an application of load after the first application. If this spring line is moved until it starts at the same point with the first diagram, it will be the same diagram as would be made by a perfectly elastic test bar. In this case I have added the diagram from the $\frac{1}{2}$-inch square tempered steel bar, and it is shown by the dotted line and coincides with the spring line of the ingot iron.

Fig. 122 shows an impact diagram (25-pound swinging hammer) from a test bar cut from the same bar of ingot iron. With dead

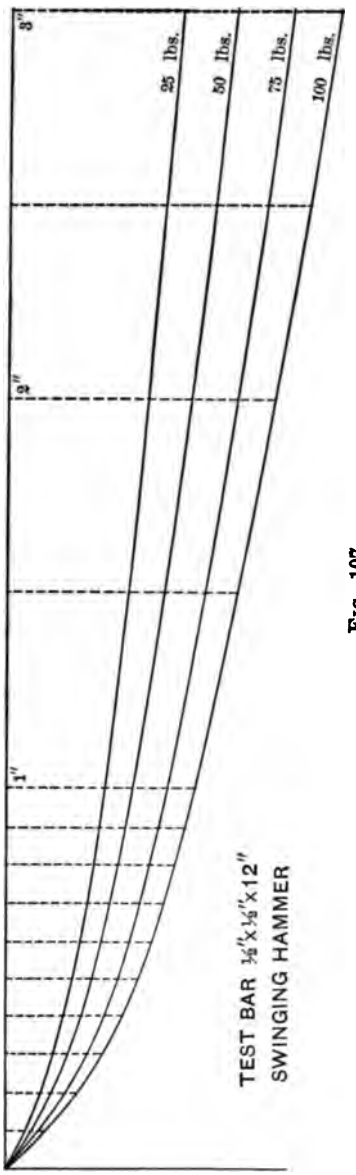


FIG. 107.

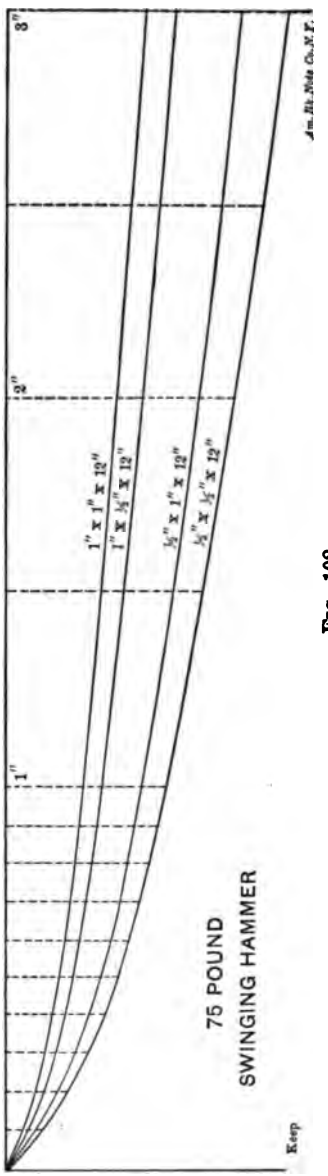


FIG. 108.

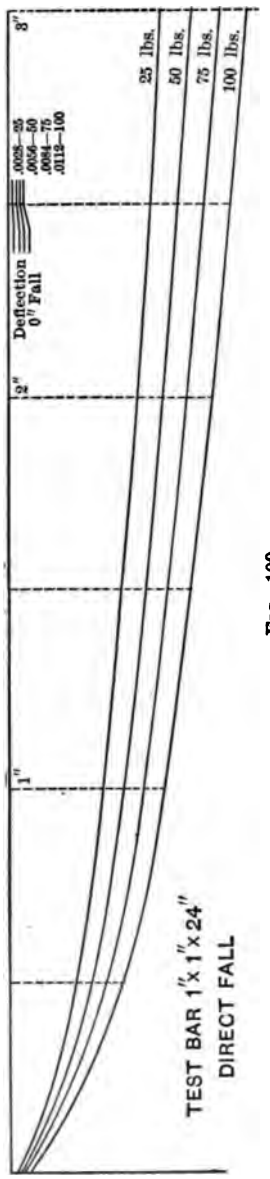


FIG. 109.

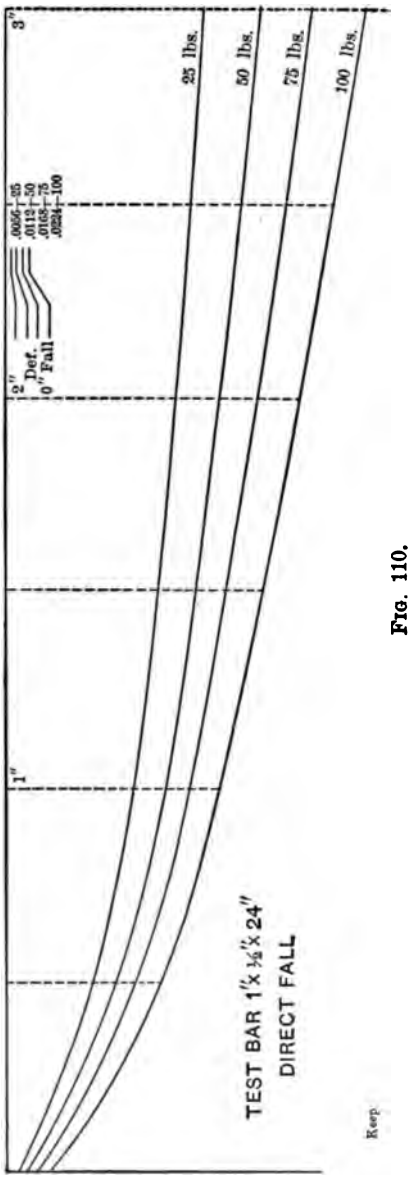


FIG. 110.

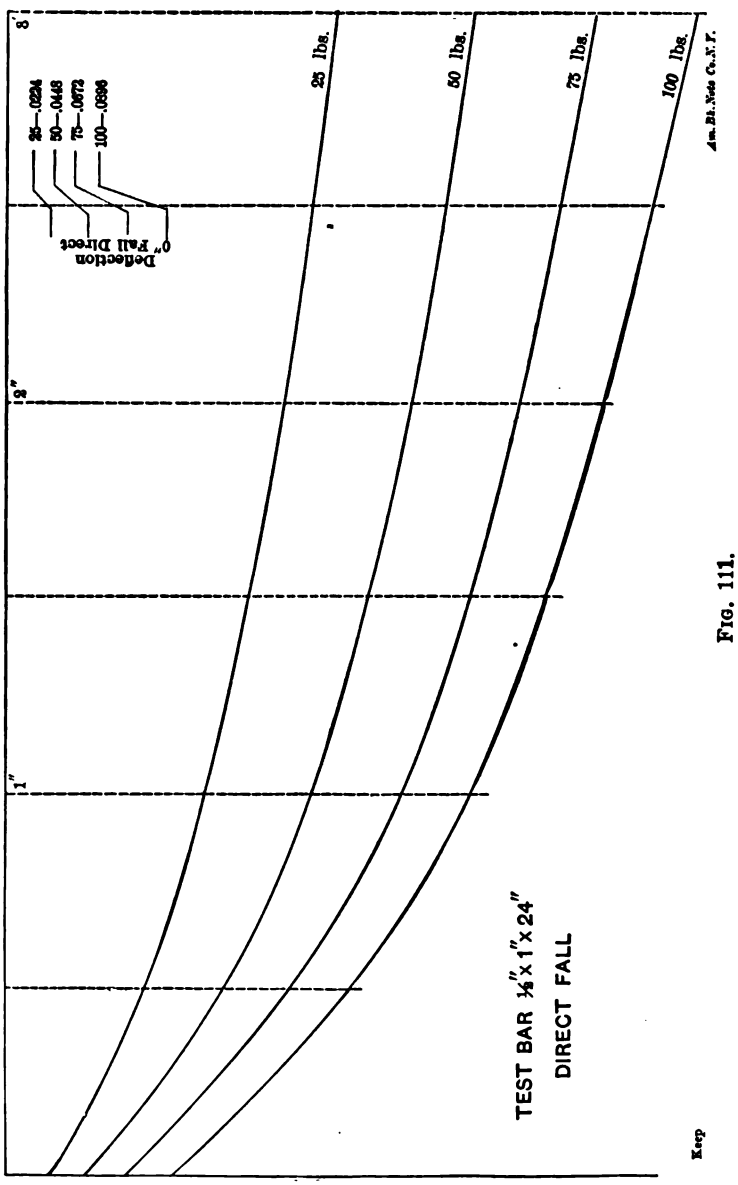

8"
3"
1"
25 lbs.
50 lbs.
75 lbs.
100 lbs.
25—.0224
50—.0448
75—.0672
100—.0896
0" Fall Direct
Deflection
TEST BAR ½"x1"x24"
DIRECT FALL
Am. Bl. Note Co. N.Y.
Kesp

FIG. 111.

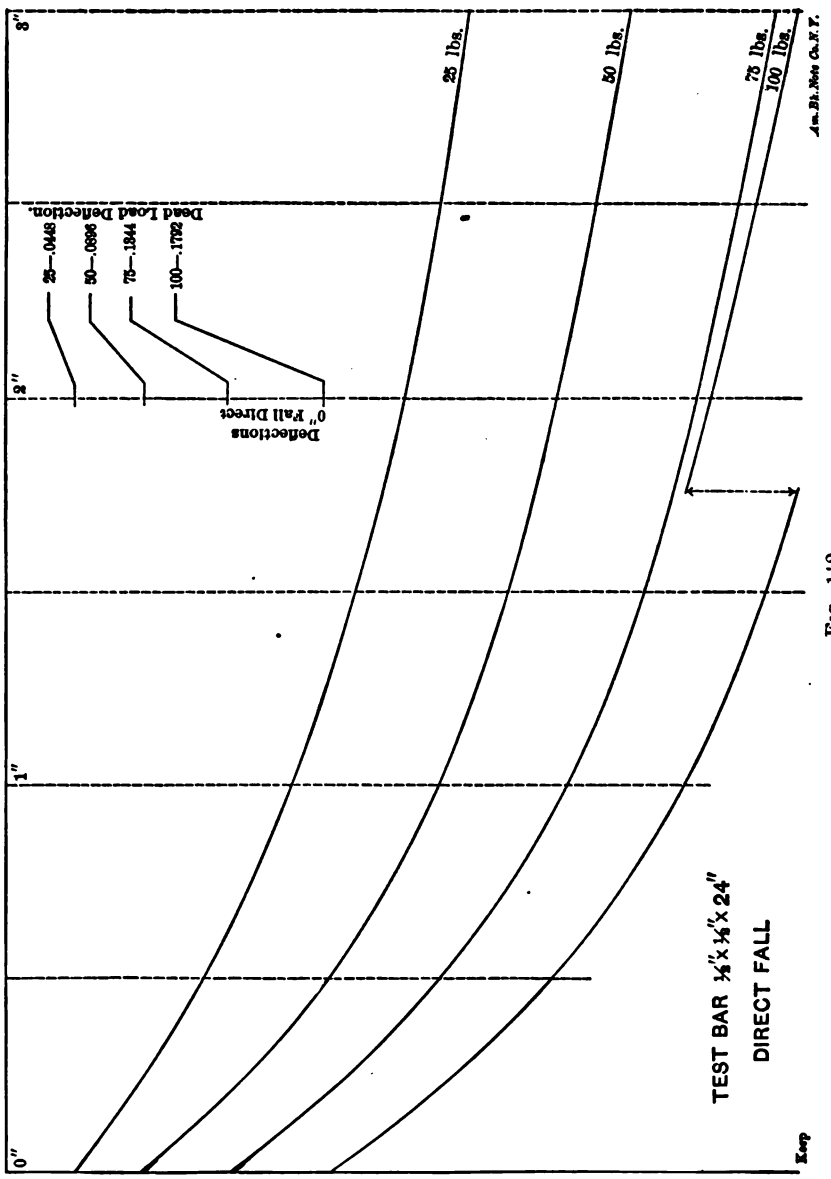

3"
2"
1"
0"
25 lbs.
50 lbs.
75 lbs.
100 lbs.
Am. Bk. Note Co. N. Y.
Dead Load Deflection.
25—.0448
50—.0896
75—.1344
100—.1792
Deflections
0" Fall Direct
TEST BAR ½" x ½" x 24"
DIRECT FALL
Kmp

FIG. 112.

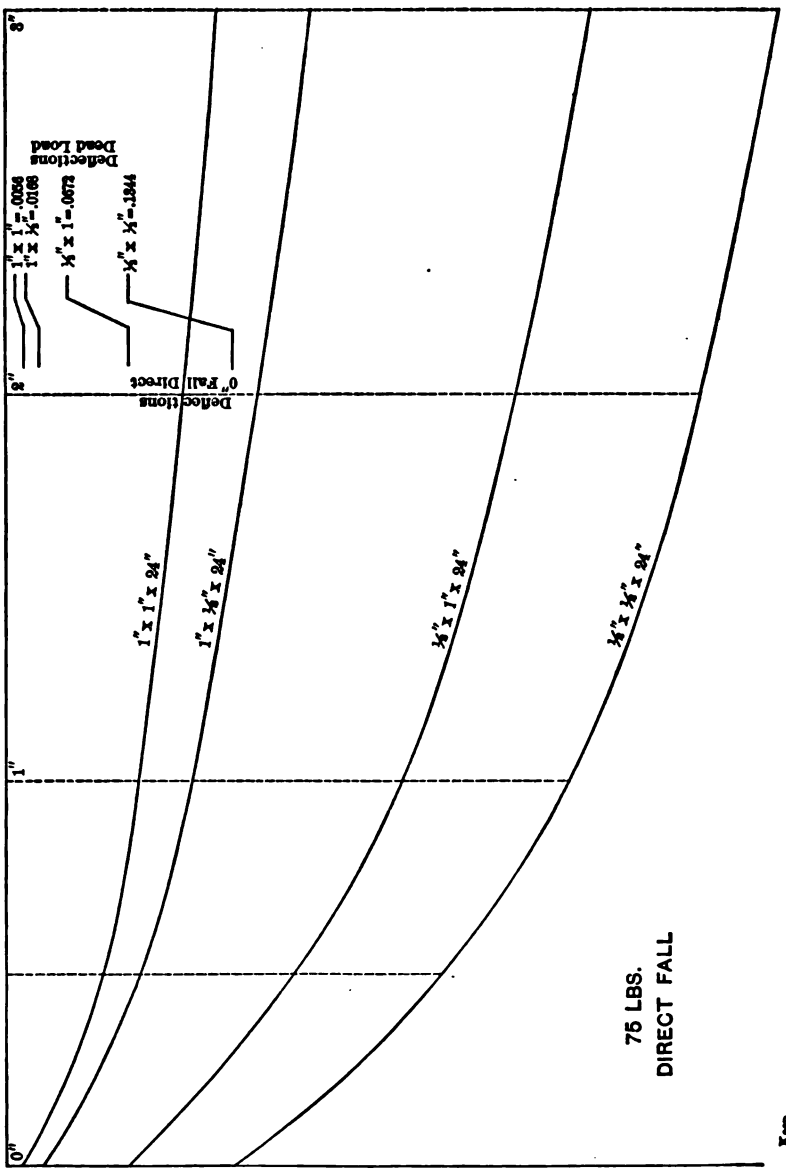

0"
1"
2"
3"
1" x 1" = .0056
1" x ½" = .0168
½" x 1" = .0672
½" x ½" = .1344
Deflections
Dead Load
Deflections
0" Fall Direct
1" x 1" x 24"
1" x ½" x 24"
½" x 1" x 24"
½" x ½" x 24"
75 LBS.
DIRECT FALL
Keep
Am. Bk. Note Co. N.Y.

FIG. 113.

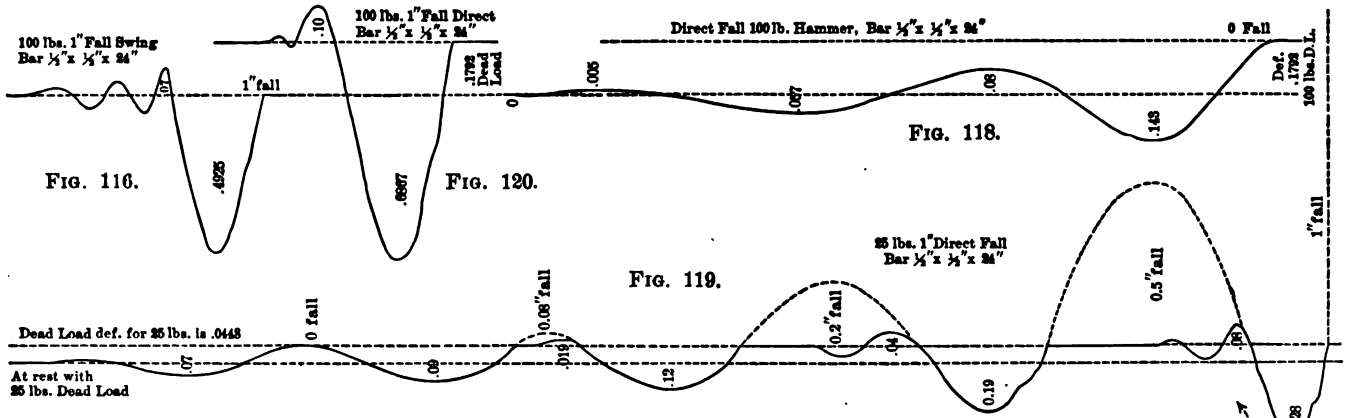


FIG. 116.

FIG. 120.

FIG. 118.

FIG. 119.

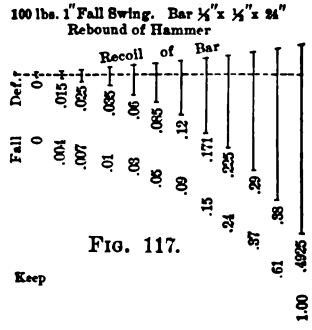


FIG. 117.

Keep

All diagrams on this page are ½ actual size.

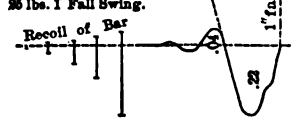


FIG. 115.

FIG. 114.

load the bar took no set until it gave way. With impact, set began almost at once. The upper line shows the vibration of the bar. I have added as dotted lines impact diagrams from the tempered steel bar. As it took no set, the line of sets coincides with the base line.

Figs. 123 and 124 are diagrams from bars of puddled iron. Figs. 125 and 126 are diagrams from gray cast iron, which takes set with the smallest load, but after having been subjected to a given load, in this case 300 pounds, it is perfectly elastic for less loads. The second application of load makes the spring line which is reproduced in the dotted line. This dotted spring line divides the total deflection into elastic deflection above it and set deflection below it. When the second diagram reaches the 300-pound mark, it takes up the line which would have been made if the load had not been removed.

In every case the deflection is greater with impact than with dead load.

Impact Tests.—To determine the resilience of a material, support a test bar at the ends and deliver blows at the centre. After a test bar has been tested in this way to find its resistance to impact without any distortion as a test of brittleness, a portion of the same bar should be clamped on the anvil of the testing machine so that one end shall project (see Fig. 137). Blows should be delivered on the projecting end. Mr. Barba has suggested taking a test bar of steel 1.181 inches square and filing a notch in the top and bottom, making the depth at that point only 0.835 inch. The object of the notches is to prevent any deflection before fracture. For general use it would not be safe to trust to the notches being made alike in shape and depth. For cast iron it would not do to cast the notch, as in cooling the formation of the grains around the notch would greatly weaken the test bar.

For cast iron it would seem best to leave the bar with its original section, and deliver the blows as far from the clamp as $1\frac{1}{2}$ times the depth of the bar, which would be the proportionate distance suggested by Mr. Barba. An inch bar would receive blows $1\frac{1}{2}$ inches from the clamp and a $\frac{1}{2}$-inch bar $\frac{3}{4}$ inch from the clamp.

Size of Test Bars for Impact.—Some *one size* of test bar must be selected for comparisons. The size for cast iron which would seem to give the best results is a bar 1 inch by 1 inch by 24 inches struck with a 50-pound hammer. This has the same relative proportions as a bar $\frac{1}{2}$ inch by $\frac{1}{2}$ inch by 12 inches, and if a 25-pound hammer is

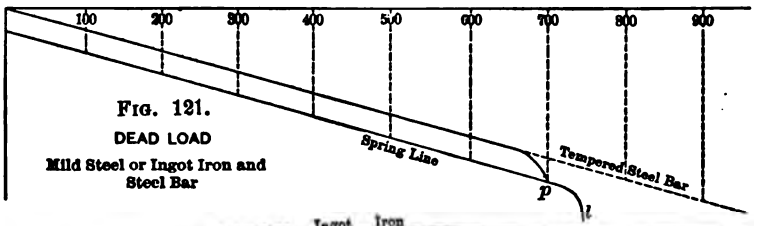


FIG. 121.
DEAD LOAD
Mild Steel or Ingot Iron and Steel Bar

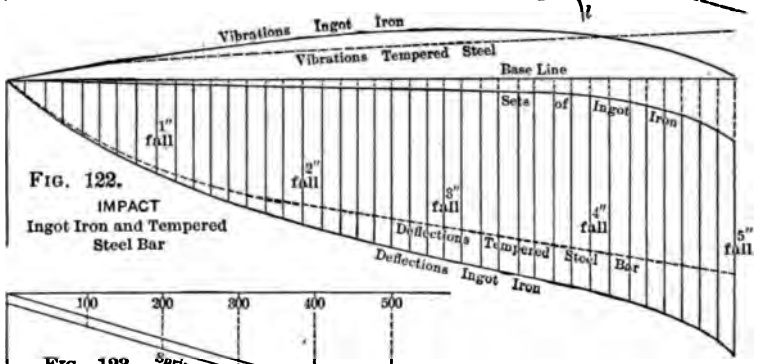


FIG. 122.
IMPACT
Ingot Iron and Tempered Steel Bar

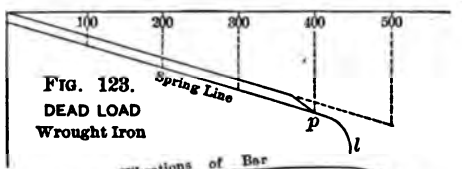


FIG. 123.
DEAD LOAD
Wrought Iron

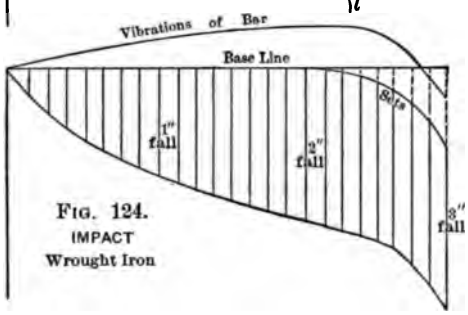
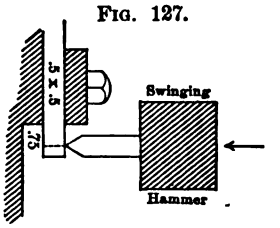


FIG. 124.
IMPACT
Wrought Iron

FIG. 127.



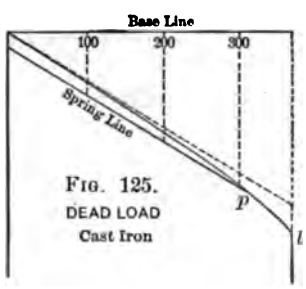


FIG. 125.
DEAD LOAD
Cast Iron

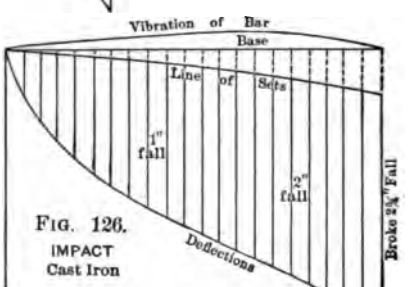


FIG. 126.
IMPACT
Cast Iron

All Test Bars on this page are ½" x ½" x 12," all Impacts are with a 25 lb. Swinging Hammer, all diagrams Full Size. Deflections multiplied by 5.

used, the record is the same as with a 1 inch by 1 inch by 24-inch bar with a 50-pound hammer; but this does not take into account the change in grain due to size of casting.

Impact with a Swinging Hammer.—The swinging hammer appears to be the best mode of application of impact for ordinary test bars.

Its convenience is greatly in its favor. It does not affect the surface of the test bar. The height of fall is exact to $\frac{1}{8}$ inch. It can be operated by hand rapidly.

Blows should be begun with the same drop at all times, which should be less than the lowest possible breaking drop, and then each drop should be increased by $\frac{1}{8}$ inch until fracture takes place.

DISCUSSION.

Prof. Mansfield Merriman.—The experiments of Mr. Keep are interesting and valuable, and the tables of dynamic deflections, given on pages 375 and 376, are in as reasonable accord with theory as could be expected with such specimens and apparatus. The theoretic formulæ for deflection under impact, when the elastic limit is not exceeded, are deduced on pages 251 and 253 of the writer's "Mechanics of Materials." These formulæ are:

for the swinging hammer, $$\delta = \sqrt{\frac{2h\Delta}{1 + \frac{17W}{35P}}},$$

for the direct hammer, $$\delta = \Delta + \sqrt{\frac{2h\Delta}{1 + \frac{17W}{35P}} + \Delta^2},$$

in which δ is the dynamic deflection required, W the weight of the bar, P the weight of the hammer, Δ the static deflection under the dead load P, and h the height of fall of the hammer. For a light bar the quantity $\frac{17W}{35P}$ is small and may often be neglected, in which case the formulæ become:

for the swinging hammer, $\delta = \sqrt{2h\Delta}$,

for the direct hammer, $\delta = \Delta\sqrt{\frac{2h}{\Delta} + 1}$.

By means of these formulæ the dynamic deflections observed in the experiments may be compared with the theoretic values.

The following is such a comparison for the $1'' \times 1'' \times 24''$ bar, the values of Δ being taken from the dead-load tests on page 373, and the fall h being 2 inches:

For load P	=	25	50	75	100 pounds.
Static deflection Δ	=	0.0028	0.0056	0.0084	0.0112 inch.
A Computed deflection δ	=	0.100	0.145	0.180	0.209 "
A Observed deflection δ	=	0.122	0.150	0.175	0.200 "
B Computed deflection δ	=	0.103	0.151	0.188	0.220 "
B Observed deflection δ	=	0.130	0.159	0.181	0.209 "

in which the results A are for the swinging hammer, while B are for the direct hammer. It is seen that the agreement is very satisfactory.

For the smaller bars, however, the agreement seems not to be as good, the observed values being in the following case all much less than the theoretic ones. This case is for the $\frac{1}{2}'' \times \frac{1}{2}'' \times 24''$ bar, and for a fall of 2 inches:

For load P	=	25	50	75	100 pounds.
Static deflection Δ	=	0.0448	0.0896	0.1344	0.1792 inch.
A Computed deflection δ	=	0.417	0.594	0.725	0.847 "
A Observed deflection δ	=	0.322	0.470	0 600	0.705 "
B Computed deflection δ	=	0.420	0.601	0.737	0.866 "
B Observed deflection δ	=	0.418	0.578	0.720	0.851 "

It is safe to say, if impact tests be made on perfectly homogenous specimens within the elastic limit, and if all sources of error in the apparatus be eliminated so that the entire energy of the falling hammer is communicated to the specimen, that the observed dynamic deflections will agree with those computed from the above theoretic formulæ.

Prof. J. B. Johnson.—The only interest which would seem to attach to Mr. Keep's results of impact tests lies in the comparison which may be instituted between his actual results and the results which could have been predicted from purely theoretical considerations. Thus from his Table I., in which deflections are given for static loads, the modulus of elasticity of the material can be found for the one-inch square bar 24 inches long. This modulus, E, equals 30,800,000. Using this modulus for the impact tests and assuming that all the energy of the blow enters the specimen, and taking the 100 pounds swinging hammer having a fall of 3 inches, we may make the following computations:

Energy of hammer on striking the bar equals 300-inch pounds (less frictional loss).

Record deflection under this blow equals 0.24 inch.

The static load which would have produced the same deflection may be found from Table I. by computation to be 2,140 pounds.

The energy which was absorbed by the specimen, therefore, was one-half the product of these two quantities, which is 257-inch pounds.

We see, therefore, that $\frac{257}{300}$, or 86 per cent. of the theoretical energy of the swinging hammer, entered the specimen in this test. This is a high percentage for impact tests and indicates that the tests were well made and that the anvil supports of the test specimen were reasonably large. It is, of course, impossible ever to insure that all of the energy of the blow is absorbed by the test specimen. With carelessly devised experiments, it sometimes does not exceed from 5 to 10 per cent. of the energy of the blow.

In case no static tests had been made for deflections, these could have been computed from the general formulæ commonly used for that purpose, since the modulus of elasticity of steel is well known to be always within about 5 per cent. of 30,000,000 pounds per square inch. Thus for a rectangular bar, loaded at the centre and supported at the ends, the deflection equals $\frac{P1^3}{48EI}$; or, in terms of the stress on the extreme fibres, the deflection for this case equals $\frac{f1^2}{6Eh}$, from which the stress on the extreme fibres can be computed for a particular deflection. Thus for a deflection on this bar of 0.240 inch, the stress on the extreme fibres is 77,000 pounds per square inch, this corresponding to a static load as given above of 2,140 pounds.

From this stress on the extreme fibres we could compute at once the amount of energy required to develop this stress by an impact test. Thus we have for a rectangular bar, struck at the centre, the resilience or energy absorbed by the bar in inch-pounds, equals $\frac{1}{18}\frac{f^2}{E}$ multiplied by the volume of bar in cubic inches.* This formula indicates that the energy entering the bar varies as the square of the stress of the extreme fibres; but as this stress on the extreme fibres varies directly with the deflection inside the elastic limits, we may say that the energy

* See Johnson's "Materials of Construction," page 84, Eq. (6).

entering the bar varies directly with the square of the deflection produced. From this we may also make the contrary statement that the deflection will vary with the square root of the energy absorbed. Now the energy absorbed is always a product of the average force applied to the bar into the final deflection of the bar, but as this force begins with zero and increases uniformly to a maximum for the final deflection, the average force is always, inside the elastic limits, one-half the final force which corresponded to the maximum deflection. We may say, therefore, that the energy absorbed in inch-pounds by the bar is always equal to one-half the product of the final resistance in pounds into the final deflection in inches. It matters not whether this energy may be produced by a greater weight falling a shorter distance or *vice versa*. Thus a 100-pound weight falling 3 inches has acquired the same energy as a 300-pound weight falling 1 inch, the energy in each case being 300 inch-pounds. Let us therefore institute two kinds of comparisons with Mr. Keep's tests.

First, let us compare deflections produced by the same weight falling different distances; and, *second*, let us compare deflections produced by different weights falling the same distance.

CASE I.

Same Weight Falling Different Distances.

Assume a weight of 100 pounds falling one inch, and 100 pounds falling 3 inches. In the former case the energy acquired is 100 inch-pounds and in the latter it is 300 inch-pounds; but since the deflection varies as the square root of the energy, the deflection in these two cases would vary as 1 to the square root of 3, or as one and seventy-six hundredths. We would expect, therefore, to find that the deflections under the 3-inch drop would always be one and seventy-six hundredths times the deflection under the 1-inch drop. Similarly, the deflection under a 2-inch drop should be just twice that under a $\frac{1}{2}$-inch drop. That is to say, if the distances be plotted for increasing distances of fall for a given weight, these points would fall upon a parabola, and this they very nearly do in Mr. Keep's test. His curves for given weights will be found to very nearly satisfy this law.

CASE II.

Varying Weights with a Fixed Fall.

If we take weights of 25 pounds and of 100 pounds falling the same distance, the energies in these two cases would be as 1 to 4, and the corresponding deflections would therefore be as 1 to 2; in other words, for a given drop the deflections vary as the square root of the weights. Mr. Keep does not show such a curve, but if such curves be plotted they would also prove to be parabolas, the same as the curves shown for the equal weights with varying distances of fall.

It should not be expected that any series of impact tests would exactly satisfy these theoretical requirements, since the whole energy of the blow never enters the specimen, and varying proportions of this energy would be found to have entered the specimen and to have been absorbed by it for the different weights and the different distances of fall; furthermore, when the weight consists of a hammer falling directly and freely upon the specimen vertically downward, the energy acquired by the falling weight under the force of gravity is the product of the weight in pounds into the total fall, which is the original height above the specimen plus the deflection of the specimen under the impact.

Comparisons, therefore, in the two cases given above should be instituted with the results given by the swinging hammer of Table II., rather than with the results given in Table III. If we are to test the theory by the results given in Table III., we must in each instance add the recorded deflection to the "height of fall" there given, and use this as the "total height of fall" in each instance. By adding this we will find that this table will give as consistent a set of results as Table II. Thus, if we were to compare theory with fact, with the ½-inch square bar, 24 inches long, under the direct fall of a hammer dropping 1 inch and 3 inches (Table III.), we would have:

Deflection at 1 inch : deflection at 3 inches : : the square root of 1 inch + deflection : square root 3 inches + deflection.

Solving this proportion for the four loads, 25, 50, 75, and 100 pounds respectively, and computing deflection under the 3-inch

drop from the observed deflection under the 1-inch drop, I find them to be 0.490, 0.720, 0.901, and 1.070, as compared to the observed deflection of 0.482, 0.652, 0.800, and 0.941 respectively. That is to say, the observed deflections under the 3-inch drops were somewhat less than they should have been to satisfy these theoretical requirements. This simply means that a greater proportion of the energy under the 3-inch drop was lost by friction and by dissipation of the energy of the blow, and so failed to enter the specimen, than was the case under 1-inch drop. This is as it should be, since the velocity of the weight on striking the specimen was much greater under the 3-inch drop than under the 1-inch drop. It is evident that the higher the velocity of the striking weight the greater the proportion of this energy which will be lost by dissipation in various ways; or, to put it in another way, for a given amount of energy in a striking weight, a greater proportion of this energy will enter the test specimen if the striking weight is moving slowly than it will if the striking weight is moving rapidly. In other words, a 400-pound weight falling one inch will give a greater portion of this energy over to the test specimen than would a 100-pound weight falling four inches, although the energy of the two bodies on striking the specimen would be the same. Therefore we should expect to find greater deflections under a 400-pound weight falling one inch than under a 100-pound weight falling four inches. By applying this criterion to Mr. Keep's Table II., it will be found that within the limits of this table the same energy gives usually about the same deflection.

I cannot see that this paper is any contribution to the science of the strength of materials. It is a contribution to the science of the testing of materials in so far as it shows what can be done in making impact tests with the appliances used.

The experiments have evidently been made with the greatest care, and I doubt if they could be improved upon. They may be accepted, therefore, as indicating the nearest approach which can reasonably be expected of actual experimental results of impact tests to the theoretical deductions derived from static tests. It perhaps need not be said that no direct comparison can ever be instituted between static strength and the resistance to impact. That is to say, there is no meaning in the statement which is sometimes made, that so many pounds of static strength are equivalent to so many foot-pounds of resistance to impact.

Such a statement is no more rational than to say that the static force which can be exerted by an engine is a measure of its horse-power. Resistance to shock or impact results from both static strength and from the capacity of the body to deform or yield under the load. Thus india-rubber is a comparatively weak material, but it has a great capacity for absorbing energy or the force of a blow, because of its great elastic deformation. It is absolutely essential, therefore, that these two kinds of strength, namely, static strength and dynamic strength, should be rigidly differentiated in the mind, and never confused or equated one with the other. The strongest cast iron, when tested statically, may be the weakest for resisting a shock. The difficulties concerning dynamic or impact tests are also very great, and such tests should only be undertaken under the most careful and theoretically competent supervision.

No. 843.*

AN EFFICIENCY TEST OF A ONE HUNDRED AND TWENTY-FIVE HORSE-POWER GAS ENGINE.

BY C. H. ROBERTSON, LAFAYETTE, IND.

(Junior Member of the Society.)

DURING the past five years the technical press has given considerable attention to the development, theory, and construction of the gas engine. In this time comparatively few large gas engines have been built in this country, and very meagre indeed have been the published data concerning the performance of such engines. In view of this fact, it has been thought that the matter here presented would be of timely interest, and a possible addition to the present knowledge of gas-engine performances under service conditions.

The Merchants' Electric Lighting Company of Lafayette, Ind., was organized in the spring of 1896. It consisted of a few business men, who felt that they could secure more satisfactory service by installing and controlling a plant of their own than by continuing their patronage with the single large company which then occupied the field. As a result, a suitable building was secured, and there was installed a small plant with a 60 horse-power high-speed steam engine as the motive power. In a short time the capacity of this plant was inadequate, and it was decided to rebuild on a larger scale. Accordingly, in the winter of 1897–98, a new plant was designed and constructed with the rather unusual feature, in one of its size and time, that dependence was placed entirely on gas engines as the motive power.

THE PRESENT PLANT.

An exterior view of the new plant is shown in Fig. 128. The building is substantially built of brick, 60 feet long and 45 feet wide. The general arrangement is shown in the ground plan (Fig. 129), where it may be seen that the front portion is occupied

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

by an office and a repair shop, over which is a large storeroom, while an engine and dynamo room occupies the rear portion. Between the engine room and the main office is a wash room and a private office. In the engine room are two 125 horse-power Westinghouse gas engines using natural gas as fuel, and each driving a 60-kilowatt two-phase alternator of 2,000 volts with 60 cycles.

FIG. 128.

The Gas Engines.

A general view of the engine room is shown in Fig. 130. There it will be observed that the engines are of the vertical single acting type, and in general appearance are quite similar to the Westinghouse steam engine. The pipe rising from the floor immediately in front of the engine, carries gas through the diaphragm regulator to the mixing valve on the engine. The air supply is received through the pipe extending from the mixing valve to the left and up. From the mixing valve the explosive mixture is car-

ried to the cylinder by the square distribution pipe running across the front of the engine and just behind the throttle valve.

The path of the gas through the engine may well be understood by reference to Fig. 131, which shows, by a vertical sectional cut, the general arrangement of the mechanism of the engine. In this

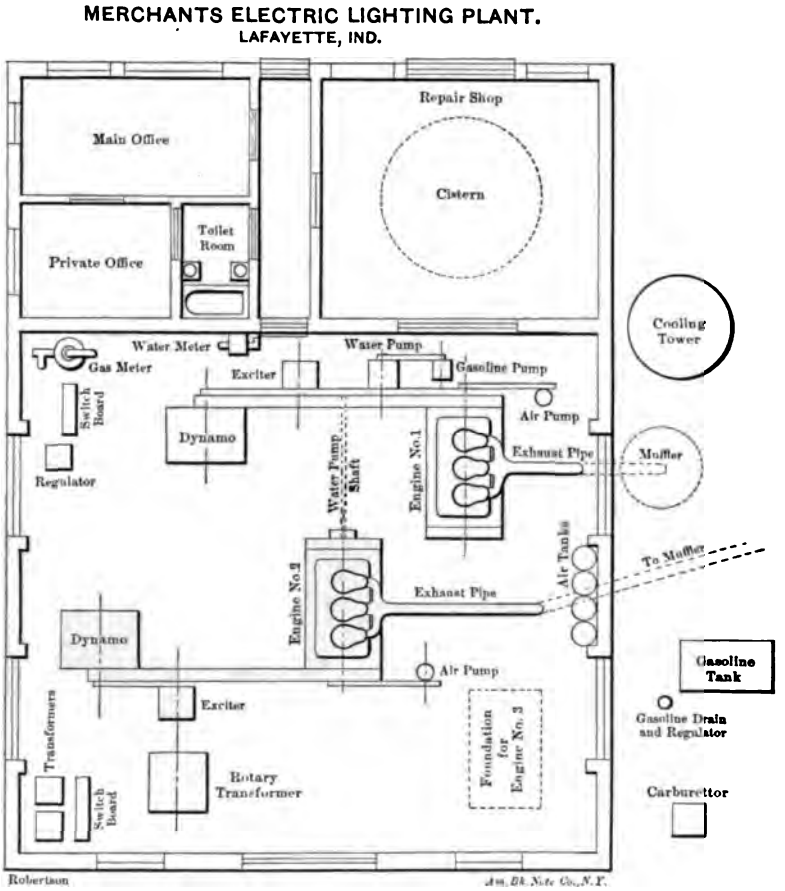


FIG. 129.

figure, the position of the piston is that found just after a charge has been exploded in the clearance space. The pressure resulting drives the piston to the bottom of its stroke, giving, of course, a half turn to the crank. During this operation the cam *A* turns one-quarter of a revolution, and, just as the piston starts on its return stroke, lifts the exhaust valve *E*. During the return of the

piston the spent gases escape through the exhaust pipe *O*. At the beginning of the second downward stroke the exhaust valve *E* has closed, and the admission valve *J* is opened by means of the cam *B* and the lever *C*. On the down stroke the mixture of gas and air enters the cylinder from the distribution chamber at *N*. When the piston reaches the bottom of its stroke the valve *J* closes, and on the return stroke the charge is compressed into the clear-

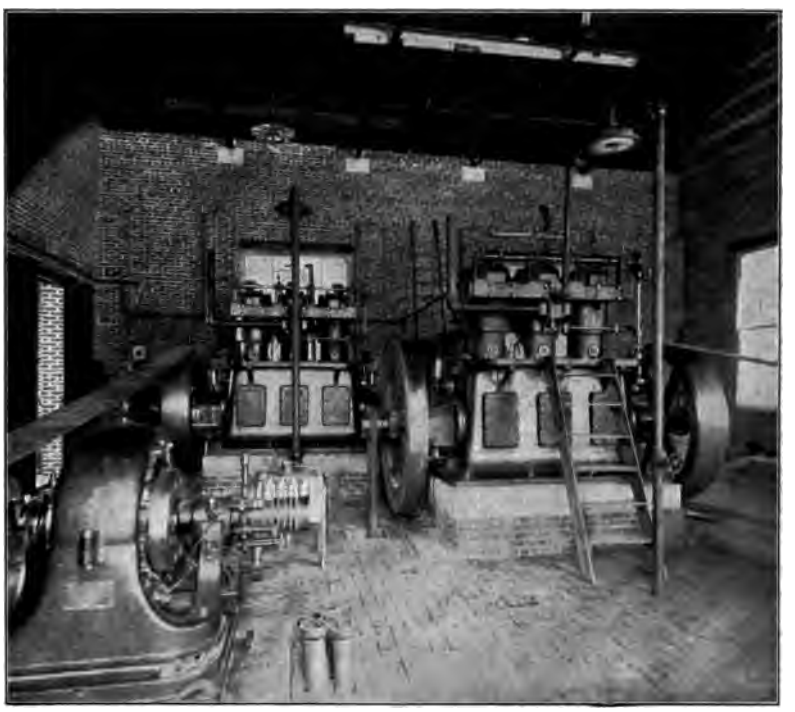


FIG. 130.

ance space. Just at this point a cam on the same shaft as *B*, but behind it, closes, and almost immediately breaks an electric circuit at the bottom of the igniter plug *F*. The spark resulting ignites the compressed charge, and the piston is again driven down as at the beginning. The cycle is thus seen to be that of M. Beau de Rochas, quite generally called, in this country, the Otto cycle. It is evident that an explosion occurs in each cylinder every two revolutions. An outline view of the engine is shown in Fig. 132. The pistons have a diameter of 13 inches and

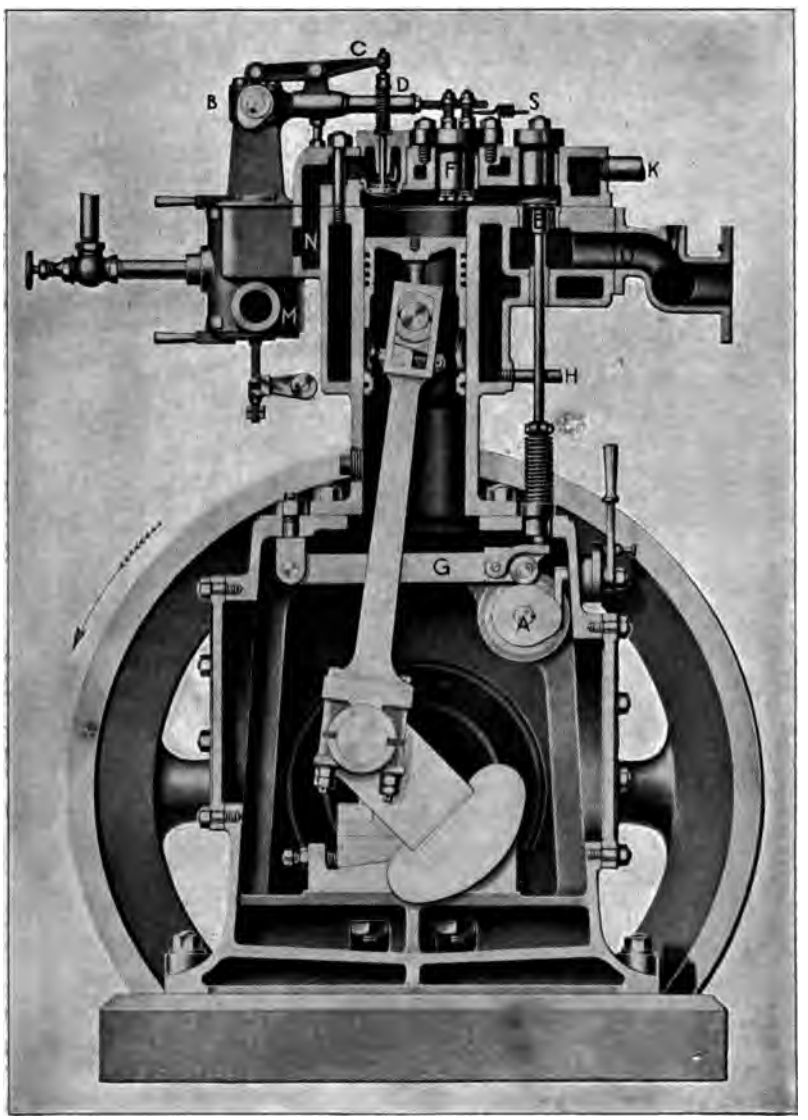
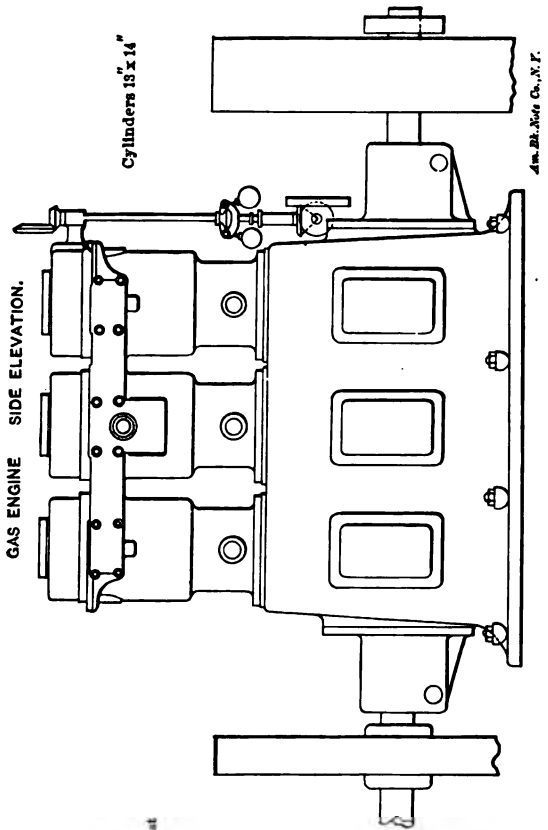


FIG. 131.

a stroke of 14 inches. The clearance, as determined by putting the engine on dead centre and filling with water, was as follows:

Cylinder No. 1	21.59 per cent.
Cylinder No. 2	21.28 "
Cylinder No. 3	21.59 "


GAS ENGINE SIDE ELEVATION.
Cylinders 13"x14"
Am. Bk. Note Co., N.Y.

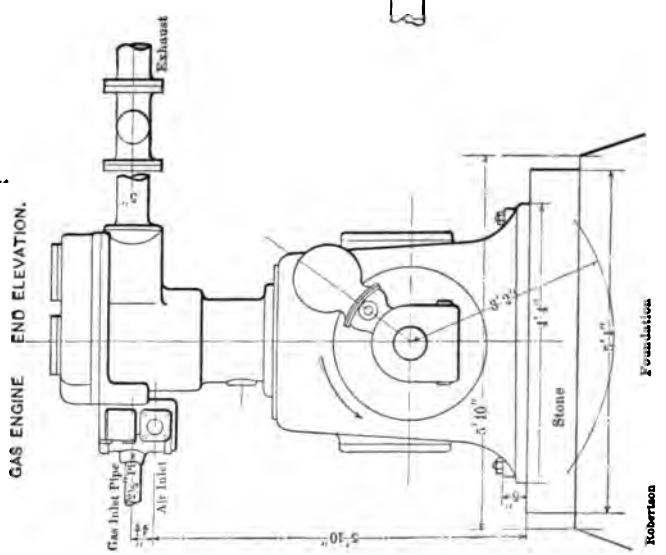

GAS ENGINE END ELEVATION.
Exhaust
Gas Inlet Pipe
Air Inlet
Stone
Foundation
Robertson

FIG. 132.

The Governor and Mixing Valve.

The gas and air on their way to the engine pass through what is known as the mixing-valve chamber, at the top and bottom of which are two horizontally moving levers, with pointers swinging over graduated arcs. The upper lever, by turning a cylindrical valve within, changes the area of the port for admitting gas. The lower lever, by means of a similar device, changes the air-admission port area. The graduations on the arcs are such as to give the ratio of gas to air which has passed to the interior of the mixing valve. Without in any way affecting the above setting, a fly-ball governor is so connected to the mixing valves as to give them a motion in the direction of their length. This motion is utilized in varying the area of the ports through which the mixture passes on its way to the cylinders. It is thus seen that the speed of the engine is controlled by throttling the mixture of gas and air without in any way affecting its quality, and that a working impulse is given every two-thirds of a revolution whether the load is heavy or light.

Starting Mechanism.

One of the cylinders of the engine is so arranged that it can be quickly and easily converted into a single-acting compressed-air engine. Assuming that the cylinder shown in Fig. 131 is to be used in this way, the action is as follows: By turning a screw on the end of the upper cam shaft, the cam B is thrown out of action, so that the admission valve J remains closed. By moving the lever seen on the outside of the crank case near the cam A, this cam is converted into a double-acting one, such that the exhaust valve E is open on every up stroke of the piston. Another cam on the same shaft A operates a valve in the compressed-air pipe, permitting compressed air to enter on every down stroke of the piston. If now the crank be placed in the proper position, and the air turned on, the cylinder will operate as a single-acting compressed-air engine. In this way momentum enough is secured to lightly compress a charge in one of the remaining cylinders, which, on ignition, augments the speed, so that the air cylinder may be thrown into its normal working condition. A very simple stop throws the compressed-air valve out of action, and a motion of the lever changes the exhaust cam to its original condition. By holding a knurled head at the end of the upper shaft, the rotation of the shaft locks the admission-valve cam in its usual posi-

tion, and the cylinder is once more operating as a gas engine. A back view of the engine is shown in Fig. 133. The exhaust-cam levers are seen at the top of the crank casing. The compressed-air pipe passes up between the crank case and the flywheel to the right-hand cylinder. In the lower left-hand corner of the picture may be seen the belt-driven air compressor. The air is stored in steel cylinders (see Fig. 134) under a pressure of 160 pounds gauge.

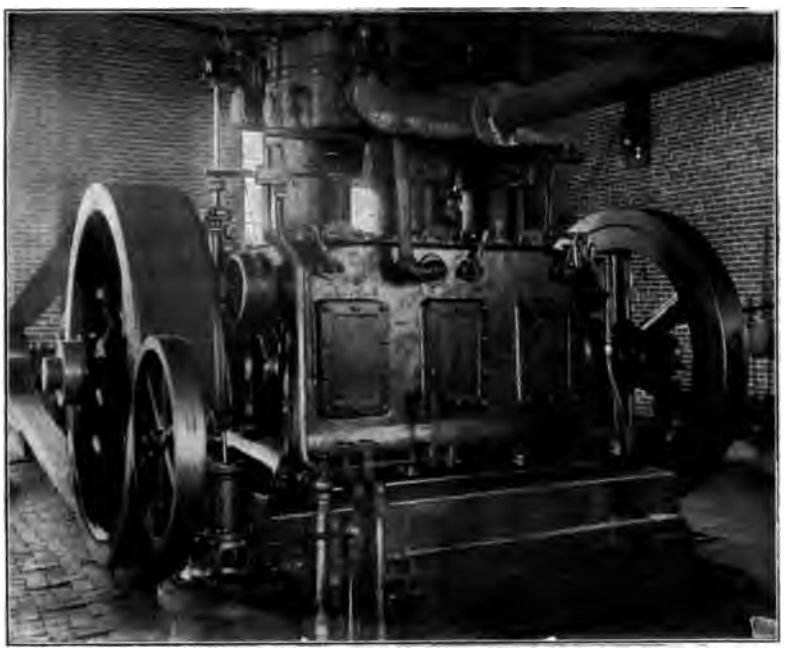


FIG. 133.

Jacket Water, Cistern, and Cooling Tower.

The cylinder walls are kept cool by the use of water jackets, the cold water entering at *H* (Fig. 131), and escaping at *K*. The plant is so piped that the city water may be used; but ordinarily a small belt-driven pump (Fig. 135) takes water from a cistern below the repair-room floor, and after passing it through the jackets, delivers it to the top of the cooling tower (Fig. 136), whence it trickles down over piled tiling to the cistern again. In passing down through the tower it is met by an ascending stream of air, from contact with which, and from a slight vaporization of itself, its heat is

carried away. No mechanical means are used for inducing the flow of air, the warming of which suffices to produce the draught.

FIG. 134.

FIG. 135.

Exhaust Muffling Chambers.

The plant is located in a portion of the city near which are many residences. It was, therefore, a matter of importance that

the noise of exhaust should not be offensive. The exhaust pipe was conducted underground to a cistern outside the building,

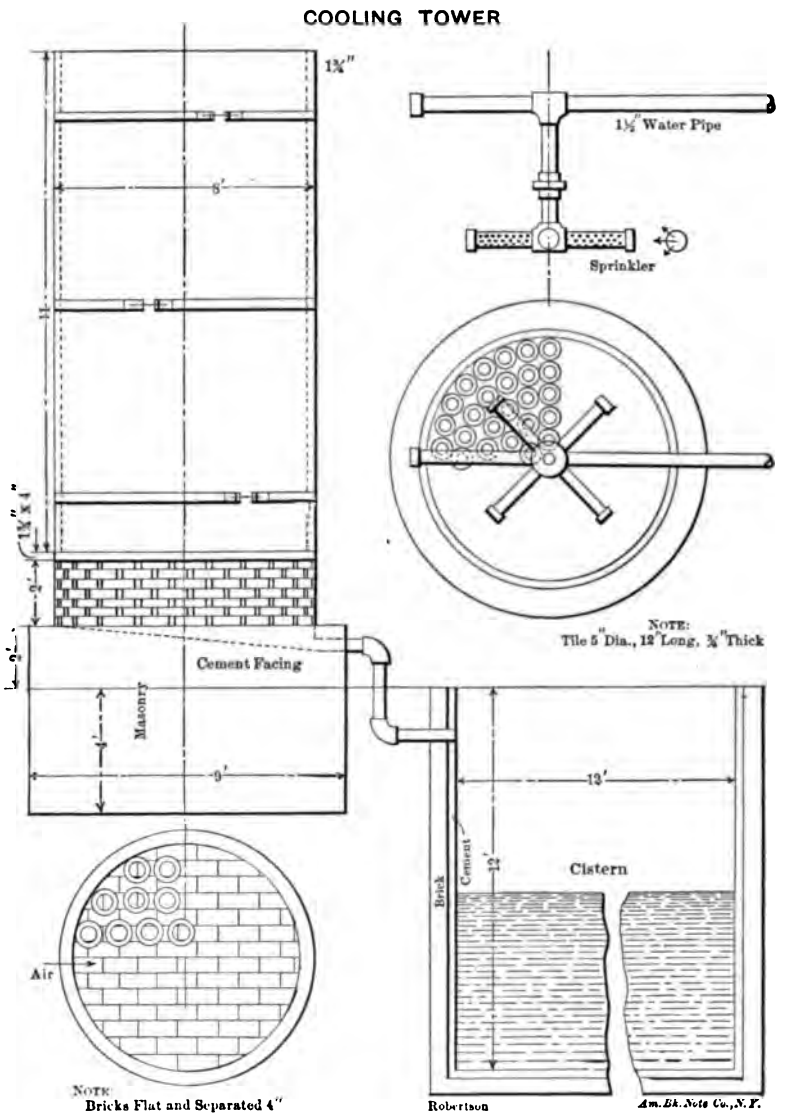


FIG. 136.

open to the air at its top through a tile of 10 inches in diameter. This worked well for one engine, the sound penetrating to a less

distance than is ordinarily the case with a high-speed steam engine. On installing the second engine, the exhaust was carried into the same cistern, and, as a result, some complaints were made, not on account of the sound, but because of the shaking of windows in buildings some distance away. The putting in of a separate cistern for this engine ended the trouble.

Gasoline Vapor Generator.

The engines ordinarily run on natural gas, but to provide against occasional interruption in its supply, a gasoline vapor generator was installed. This apparatus was placed just outside the building, and is well shown in Fig. 137. It consists of a tank for holding a considerable supply of gasoline; a small vessel, called the gasoline drain, in which is maintained, by an automatic floating valve, a constant supply from the tank; and a carburetter. The carburetter is a vertical iron pipe 16 inches in diameter, closed at both ends, and containing a number of perforated iron disks. A small rotary pump situated within the building pumps the gasoline from the drain to the top of the carburetter, from where it trickles down through the perforated iron disks and then back to the drain. On its way down it is met by a stream of air entering through four pipes at the bottom. This air, on reaching the top, is well saturated with gasoline vapor, from whence it passes to the engines. To provide the heat demanded by the refrigerating action of the carburetter, it is surrounded by a jacket through which the hot water from the engine passes on its way to the cooling tower.

The Igniters.

Two circuit breakers are mounted in each igniter plug, one being held in reserve for emergency. The igniter is operated by a cam of spiral form with a radial notch. It is so connected that just as the cam reaches its greatest throw the circuit is completed within the cylinder, to be broken an instant later by the dropping of the igniter rods into the notch of the cam.

The Tests.

The data presented in this paper were secured in March, 1899. The test was run under the personal direction of the writer, and

was the second of a series which had been planned—the first having been run in April, 1898.*

In the one under consideration the entire load of the station was thrown upon one engine, that load being the ordinary service load on one of the light days of the week. The time of the test (7.05 P.M., March 22d, to 12.05 A.M., March 23d) was so chosen as to include a considerable load variation, in order that the performance under different conditions might be observed.

Object.

The object of the test was to secure reliable data concerning:

(*a*) The power developed.

(*b*) The gas consumed.

(*c*) The speed regulation.

(*d*) Incidental; as,

(1) Heat given to jackets.

(2) Temperature of exhaust.

Indicated Horse-power.

A Crosby indicator was attached to each cylinder, one being of a special construction for gas-engine work; the others, steam-engine indicators. The springs were changed from time to time to adapt them to changes of pressure due to changing of the load.

No difficulty was experienced from the heating or lack of lubrication of indicators. In fact, they gave far less trouble than is often experienced in locomotive tests. It was not even necessary to lubricate the indicator pistons, plenty of cylinder oil for this purpose coming up from the cylinders of the engine.

The indicator rig consisted of a small set of three cranks turned from a solid piece of steel, and attached by means of a cap to the end of the engine shaft (see Fig. 138). Connecting rods and crossheads with steel wires and short pieces of indicator cord served to transmit the motion over light brass pulleys from each crank to its corresponding indicator.

---

*The writer desires to acknowledge the many courtesies of Mr. Charles Dixon, manager of the Merchants' Electric Lighting Plant; of Mr. C. C. Chapelle, formerly manager; of Messrs. G. A. Young, B.S. '99, F. Chandler, B.S. '99, and F. W. Felbaum, B.S. '99, who, as students in Purdue University, rendered painstaking aid in securing and formulating data; and to Messrs. G. W. Finney, M.E. '98, A. F. Rolf, B.S. '99, and E. L. Simpson, B.S. '99, who gave careful attention to determining the electrical output.

FIG. 137.

The electrical output was determined by experienced men with freshly calibrated apparatus.

The Gas Consumed.

The gas was measured by a wet meter of ample size. In order that the volume of gas by meter might be corrected for variations from standard pressure and temperature these two factors were observed, the one by means of a mercury "U" tube, and the

other by a Fahrenheit thermometer with the bulb exposed to the gas within the pipe leading to the meter.

Speed Regulation.

It was expected that a very careful investigation would be made

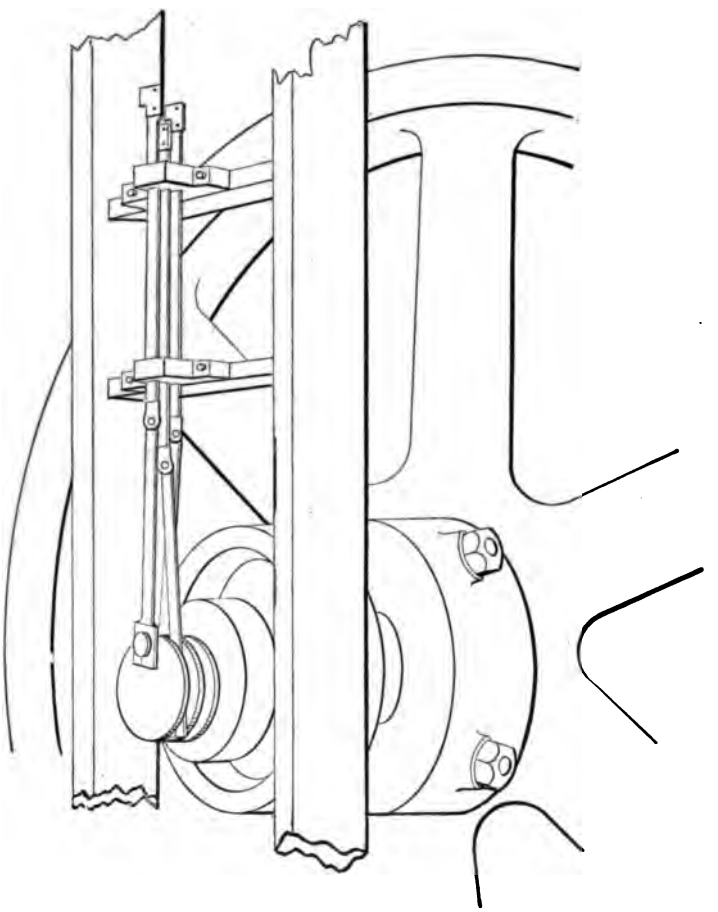


FIG. 138.

of the speed variation, and a special apparatus was designed and partially constructed for this purpose. It was not finished in time for the test, and so that part of the investigation was postponed. An attempt to use a Boyer speed recorder was not suc-

cessful, and, consequently, only the speed by a speed indicator and by a pair of revolution counters was secured.

Heat Absorbed by the Jacket.

The amount of heat absorbed by the jacket was determined by measuring the rise in temperature and the weight of water passing the jacket. For the rise in temperature, a thermometer was placed just before and just after the water passed the jacket. A thermometer was also placed in one of the barrels, where the water, on escaping from the jacket, was caught and weighed. The results calculated from the data thus secured are shown in Table I.

TABLE I.

HEAT ACCOUNT.

	B. T. U. supplied per hour.	B. T. U. converted into work. (I. H. P.)	Same in per cent.	B. T. U. absorbed by jacket.	Same in per cent.	B. T. U. exhausted per hour.	Same in per cent.	B. T. U. per I. H. P. per minute.
1st hr.	1,574,200	281,035.78	17.85	396,495	25.18	896,669	56.94	237.5
2d hr.	1,674,880	268,319.55	16.31	352,935	21.05	1,053,625	62.80	264.7
3d hr.	1,169,000	242,547.02	20.70	353,826	30.21	572,227	48.87	204.2
4th hr.	1,096,600	222,278.28	20.24	405,454.5	36.93	468,867	42.70	211.1
5th hr.	828,000	133,824.73	16.04	419,793.5	50.35	274,382	33.13	259.3

Temperature of the Exhaust Gas.

The temperature of the exhaust gases was determined by means of a copper-ball calorimeter (Fig. 139). This consisted of an arrangement which permitted of placing a copper ball in a light cage at the bottom of a thin cup-shaped pipe which projected into and a little past the centre of the exhaust pipe near the engine. After it had been in this position about an hour the cage was quickly withdrawn, and the ball dropped into a non-conducting cup containing a measured quantity of water. Special means were used for stirring and measuring the rise of temperature of the water. Knowing the weight and specific heat of the copper ball, its initial temperature was easily found. No correction was attempted for the radiation during the fraction of a second required to transfer the ball from the pipe to the cup. The results are shown in Table II.

TABLE II.

TEMPERATURE OF EXHAUST—COPPER-BALL CALORIMETER.

Time.	Weight of Copper Ball after Test. Grams.	Weight of Copper Cup. Grams.	Weight of Water.	Initial Temperature of Water. F.°	Final Temperature of Water. F.°	Temperature of Exhaust.
9:00	69.325	160.26	249.59	52	80	1,209.0
10:10	69.325	160.26	249.59	54	80	1,126.5
10:35	69.325	160.26	249.59	54	80	1,126.5
11:45	69.325	160.26	249.59	58	82	1,048.0

Observations.

Indicator cards and most of the observations were taken every five minutes. After the test, all thermometers and indicator

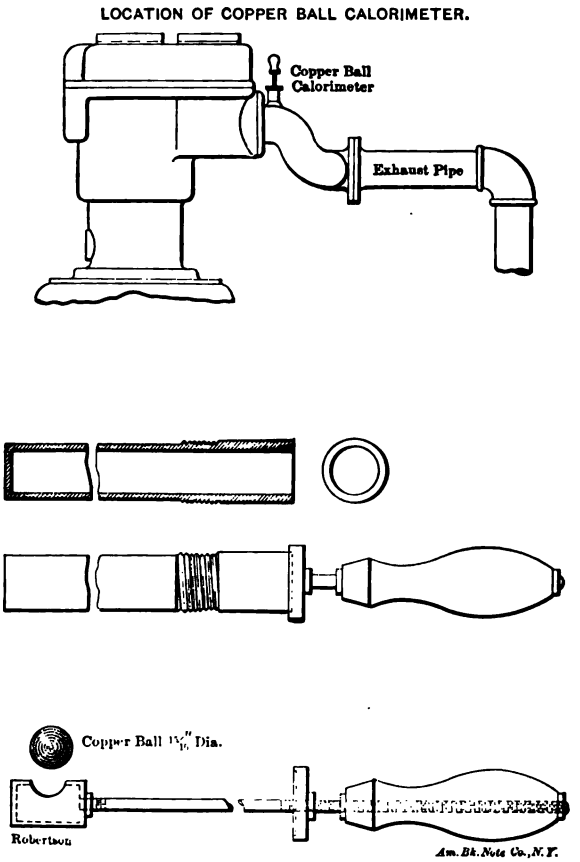


FIG. 139.

springs were carefully calibrated, but no errors of importance were found. A chemical analysis of the natural gas gave the following results:

NATURAL GAS USED AS FUEL.

Carbon dioxide (and H_2S)	1.80 per cent.
Oxygen	0.70 "
Hydrocarbon	0.50 "
Carbon monoxide	0.55 "
Hydrogen	0.60 "
Methane	92.05 "
Nitrogen	3.80 "
	100.00

A sample of the exhaust gas was taken, but was not satisfactory on account of a leak in the apparatus.

Miscellaneous Facts about the Test.

The plant was not put in especially good condition for the test, and there was no attempt on the part of the writer to secure better economy by changing the conditions from those ordinarily observed by the attendant, the desire being to secure data under ordinary service conditions. From the beginning of the test, 7.05, to 9.15, the mixing valve was set so as to give a mixture of gas to air of 1.11. At this time the ratio was changed to 1.12, remaining thus to the end of the test.

At about 8.30 one of the observers accidentally changed the setting of the mixing valve, making the mixture rich in gas. The readings of the gas meter at once indicated some change in the engine, and in a short time it was located and corrected.

At 7.40 the engine "back fired," so that two sets of indicator cards were lost.

The thermometer used for measuring the final temperature of the jacket water was broken, making it necessary to use the temperature from the thermometer in the weighing barrel in its stead. The temperature of the room was taken near and at the same height as the air "intake" pipe to the engine.

DATA AND METHODS OF CALCULATING RESULTS.

In Table III. is given an abridged collection of data and calculated results. A great many of the items of the table are also shown graphically in Fig. 140.

Referring to the table, it will be seen by column 1 that the test

was begun at 7.05 in the evening, and that observations were taken every five minutes until 12.05 A.M.

Revolutions per Minute.

In column 2 may be seen the revolutions per minute as observed with a hand speed indicator. This was taken by the same man throughout the test. The average of the 60 observations is 270.86. Two revolution counters attached to the engine and run during the test gave average revolutions per minute of 270.22 and 270.28. The highest speed in the column 2 is 280, while the lowest is 265, a total difference of 15. This, in per cent. of the average (270.86), is 5.5. The per cent..variation above the average is 3.3, while below it is 2.19.*

Temperature of the Room.

The temperature of the room is found in column 3. It was taken with a Fahrenheit thermometer on a level with, and quite near to, the "intake" end of the air-supply pipe.

Gas Measurement.

Column 4 exhibits the readings of the gas meter, while column 5 shows by differences from column 4 the amount of gas used per five minutes. Columns 6 and 7 show the temperatures (degrees Fahr.) and the pressures (inches of mercury above the atmosphere) of the gas in the pipe just before it entered the meter. Column 8 shows the gas per ten minutes reduced to 14.7 pounds and 62 degrees Fahr. It is put down per ten minutes for reasons explained under the heading "Averaging and Calculating." In columns 9 to 18, inclusive, are shown the pressures from indicator cards, some of which are shown in Figs. 141 to 143. Looking at column 18, it may be observed that the maximum indicated horse-power, 113.05, occurred at 7:20, and that from that time there was a general decrease to 39.8 indicated horse-power at 12:05. Looking next at the column 9, where are shown the compression pressures, we see that the decrease of indicated horse-

* It was the opinion of the engineer at the beginning of the test that the governor was not working properly. The fact that the engine back fired during the test indicated a defective condition, and one generally unfavorable to good governing. At the same time, it may be said that a 24-hour test run about a year before this one gave approximately the same variation—the highest reading during the 24 hours being 280 and the lowest 262.

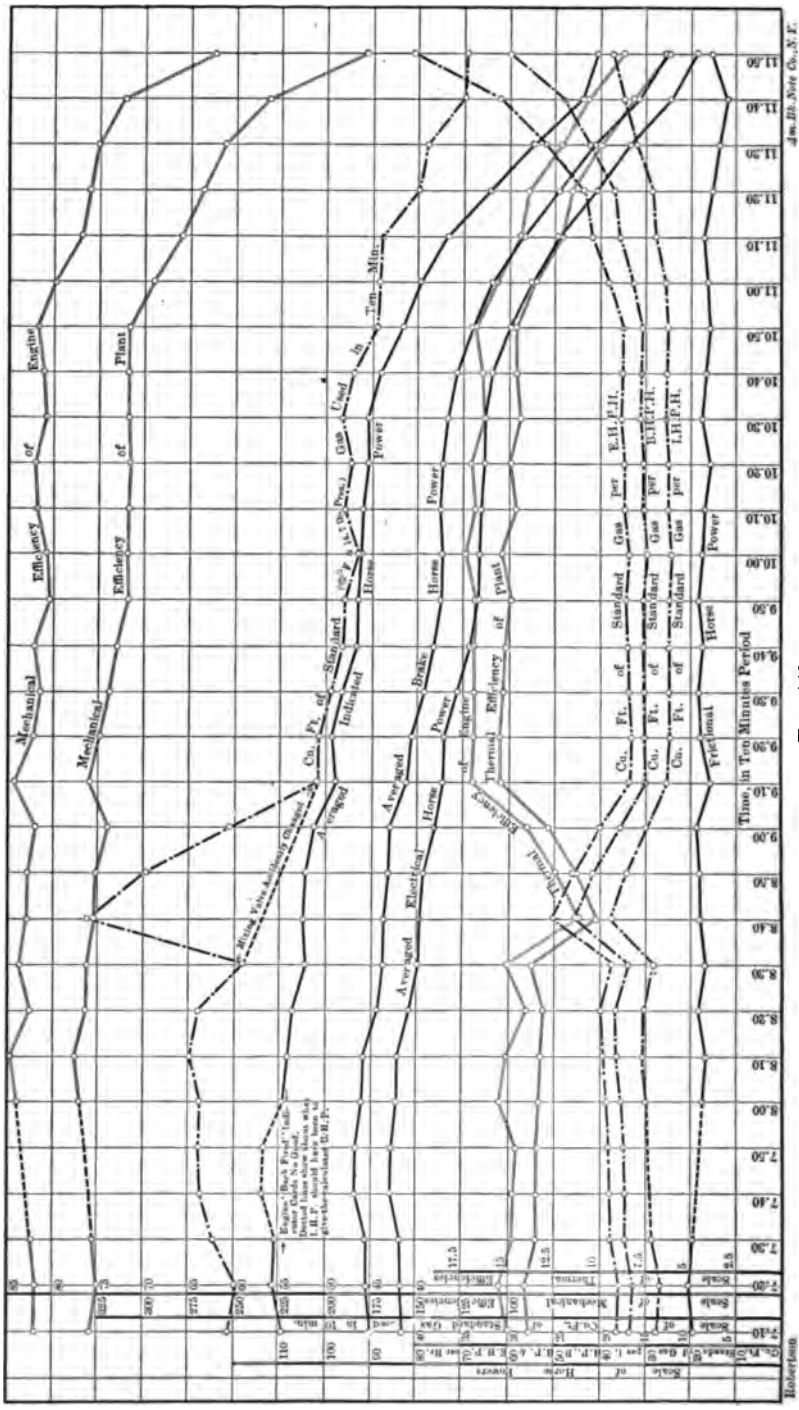
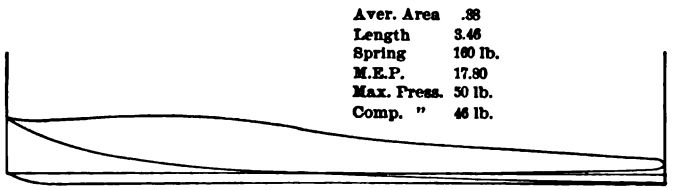


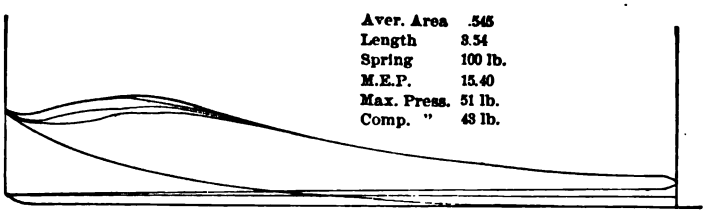
FIG. 140.

SAMPLE CARDS

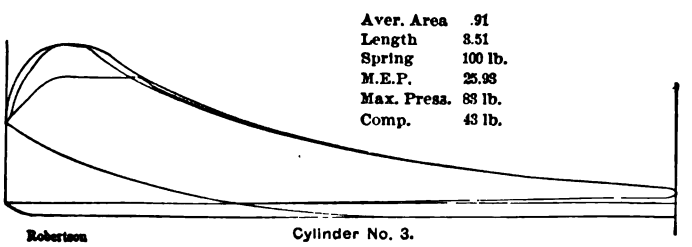
Reading No. 60.—Minimum Total I.H.P. 37.82



Cylinder No. 1.



Cylinder No. 2.



Robertson

Cylinder No. 3.

FIG. 141.

power is accompanied by a decrease of the compression pressure. This is, of course, due to the throttling action of the governor, which at low horse-powers results in a fair vacuum in the cylinder at the point where compression begins. This throttling action is well illustrated by the card from cylinder No. 3 (Fig. 141), in which the mixture was drawn into the cylinder at about 8 pounds below the atmosphere.

At 7.40 cylinders No. 1 and No. 2 were temporarily out of action. The effect on the compression pressure of cylinder No. 3 was at once apparent, it going up to 111 pounds. A like effect was manifest at 7.45. The maximum pressures shown in the next column are extremely variable. This is true, but in a lesser degree, of the mean effective pressures. This erratic action is probably due to changes in the condition of ignition. It is well illustrated in the card from cylinder No. 1 (Fig. 143), where the maximum pressure changes from 108 pounds to 136 pounds in possibly two, and not more than three, revolutions. It is interesting to observe, also, that no matter what the condition of the lines at the beginning on these cards, after about one-third stroke the different expansion curves coincide to the point of exhaust.

Indicated Horse-power.

In this engine a working impulse is given in each cylinder every two revolutions. The usual horse-power formula for one cylinder would therefore reduce to I.H.P. $= \frac{PLAN}{33{,}000 \times 2}$. The total indicated horse-power would be the sum of the indicated horse-powers of the three cylinders. Since the cylinder dimensions are practically identical the total indicated horse-power would be I.H.P. (total) $= (P_1 + P_2 + P_3) \frac{PLAN}{2 \times 33{,}000} = (P_1 + P_2 + P_3)\ .00235N$. In which N is the revolutions per minute, and P_1, P_2, and P_3 are the mean effective pressures in the different cylinders. The indicated horse-powers were thus calculated, and are shown in column 18.

Averaging and Calculating.

The whole sequence of events, from the gas meter to the engine and generator, in a plant like this, follow each other so rapidly that it is entirely possible to run a satisfactory and reliable test

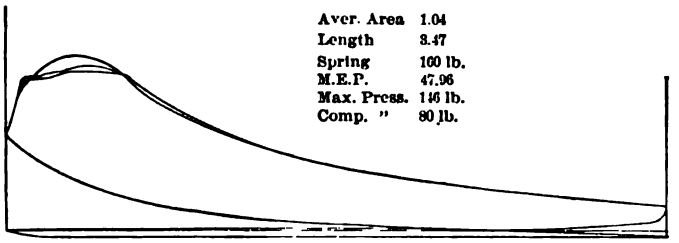
TIME.	Revolutions per Minute by Hand Speed Indicator.	Temperature of Room (Fahr.).	GENERATOR. Total Output Electrical Horse-Power.	Total Input or Brake Horse-Power of Engine.	Frictional Horse-Power of Engine.	[illegible]
1	2	3	21	22	23	
7:05 P.M.	268	77				
7:10	269	78	83.05	90.74	19.05	
7:15	269	78				
7:20	269	78	83.70	91.40	20.15	
7:25	269	77.5				
7:30	270	77	83.95	91.50	19.60	
7:35	269	76				
7:40	269	76	86.05	93.50	.....	
7:45	266	75				
7:50	265	74.5	85.80	93.35	.....	
7:55	273	74				
8:00	272	74	84.40	92.00	17.43	
8:05	268	75				
8:10	267	75	84.15	91.70	16.07	
8:15	266	75				
8:20	273	75.5	81.90	89.60	18.79	
8:25	269	76				
8:30	271	76	79.75	87.65	16.88	
8:35	265	74.5				
8:40	270	73.5	79.45	87.30	17.96	
8:45	269	73				
8:50	268	74	78.50	86.40	18.07	
8:55		75				
9:00	269	75	76.05	84.05	18.61	
9:05	269	75				
9:10	269	75	74.40	82.40	15.45	
9:15	271	75				
9:20	269	75	74.05	81.25	17.63	
9:25	270	74				
9:30	270	74	71.35	78.50	18.00	
9:35	272	74				
9:40	271	74	68.25	76.20	17.00	
9:45	270	73				
9:50	272	73	66.70	74.85	18.16	
9:55	271	72.8				
10:00	271	72.8	66.30	74.50	17.77	
10:05	271	72.5				
10:10	270	72.2	65.90	74.10	16.80	
10:15	270	72.2				
10:20	271	72.2	65.10	73.40	15.50	
10:25	271	72.2				
10:30	272	72	65.10	73.40	17.35	
10:35	273	72.2				
10:40	273	72	63.35	71.55	16.60	
10:45	273	72				
10:50	270	71.8	59.55	67.90	15.15	
10:55	273	72				
11:00	274	72	54.95	63.30	16.01	
11:05	275	71.5				
11:10	274	71.3	48.55	56.50	17.06	
11:15	270	71				
11:20	270	69.5	40.90	48.80	15.40	
11:25	278	69				
11:30	276	69	33.60	41.10	13.72	
11:35	279	69				
11:40	270	69	24.30	31.20	11.8	
11:45	274	69				
11:50	270	68.2	18.30	25.05	15.2	
11:55	271	68				
12:00	271	68	18.10	24.80	14.9	
12:05	269	68				
Totals ...	1,625.2	1,014.7	1,965.50	2,197.79	472.4	
Average..	*270.86	73.191	65.51	73.266	16.1	

: Counter No. 1, 270.28

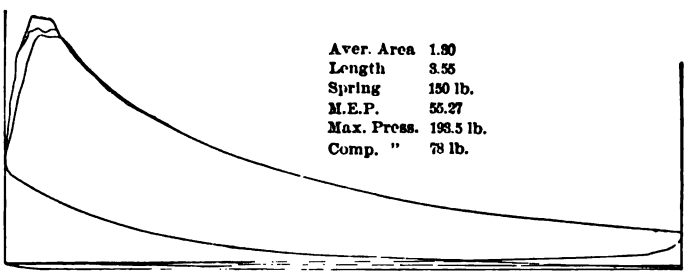
SAMPLE CARDS

Reading No. 28.

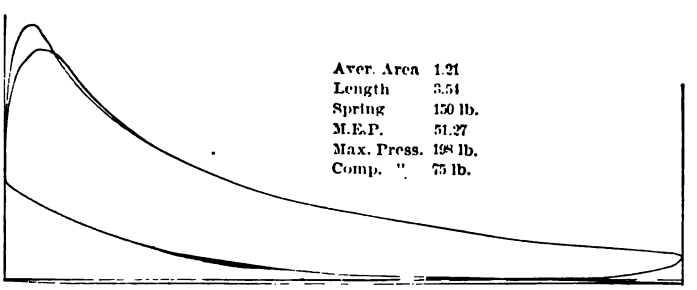
Cards of Thermal Eff. 16.84—Total I.H.P. 98.88



Cylinder No. 1.



Cylinder No. 2.



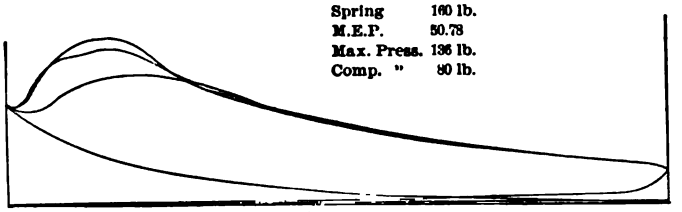
Robertson

Cylinder No. 3.

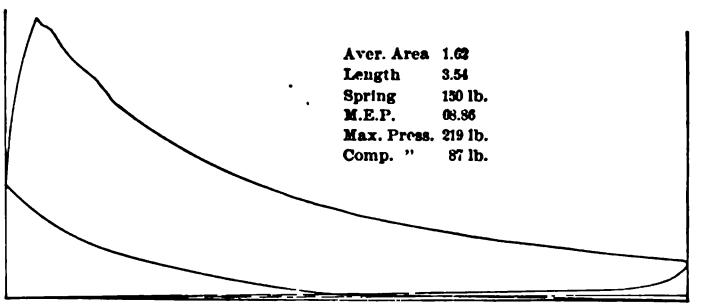
FIG. 142.

SAMPLE CARDS

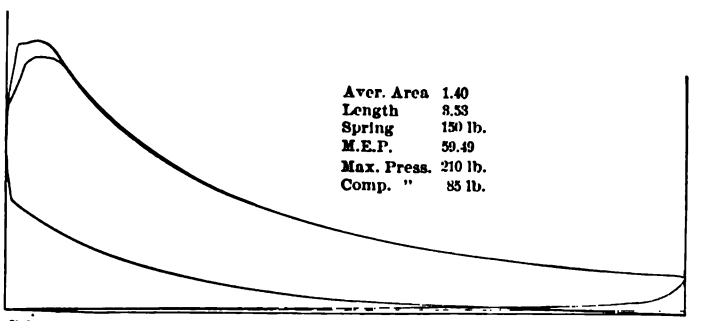
Reading No. 4.—Max. Total I.H.P. 113.05



Cylinder No. 1.



Cylinder No. 2.



Robertson

Cylinder No. 3.

FIG. 143.

of but a few minutes' duration. With this point in mind, the whole collection of data (consisting of five hours of five-minute observations) was divided up into a series of tests of ten minutes' duration, in each of which an observation was had at the beginning, in the middle, and at the end of the ten-minute period under consideration. This is illustrated in column 19 (averaged indicated horse-power), where the first figure (109.79) opposite 7.10 is the average of the three indicated horse-powers 108.20, 110.69, and 110.48, at 7.05, 7.10, and 7.15, respectively. The next reading in the same column, 111.55 at 7.20, is the average of the indicated horse-powers 110.48, 113.05, and 111.12 found at 7.15, 7.20, and 7.25, respectively.

It is, of course, apparent that the average of column 19 will not be the same as the average of column 18; the difference, however, is slight, and no more accurate way of averaging seemed available for comparing the performance of the engine under the different loads. The gas consumption for any one of the ten-minute tests was, of course, taken as shown by the gas meter for that period. The results in the remaining columns are given in this averaged way.

Generator Powers.

In columns 20 and 21 is given the generator output in kilowatts and in electrical horse-power (E. H. P.). From a previous investigation the commercial efficiency of the generator under various loads was known, which, divided into column 21, results in column 22, the power given to the generator pulley. This, neglecting under the circumstance the small belt losses, is the brake horse-power (B. H. P.) of the engine. The brake horse-power subtracted from the indicated horse-power gives the friction of the engine. The brake horse-power divided by the indicated horse-power gives the mechanical efficiency, of which the highest (84.62 per cent.) occurred at 8.10, or at the time not far from the maximum indicated horse-power. This is probably a little lower than it would be for a steam engine of the same general type and size. The frictional horse-power as an absolute quantity decreased with the decrease of indicated horse-power, but relative to the indicated horse-power, became larger and larger as the load went down. This is, of course, but another way of saying that the mechanical efficiency decreases with a decrease of indicated horse-power.

Standard Gas per Horse-power Hour.

Columns 25, 26, and 27 show the gas consumption per indicated horse-power hour per brake horse-power hour and per electrical horse-power hour. The best performance of the plant in regard to these three factors occurs at 10.00, and is per indicated horse-power hour, 11.87; per brake horse-power hour, 14.71; per electrical horse-power hour, 16.52. The highest consumption (under a mixture of 1:12) comes at 11.50, and is per indicated horse-power hour, 18.42; per brake horse-power hour, 29.65; per electrical horse-power hour, 40.59. By plotting the total gas per hour against the different horse-powers (Fig. 17), a very interesting law seems apparent. It is nothing more nor less than the parallel of the well-known Willans law for steam engines, namely, that the total steam per hour plotted against the indicated horse-power is a straight line. This has been stated to be true for at least one type of the steam turbine as well.*

Referring to Fig. 144, the solid circles show the relation between total gas per hour and the indicated horse-power. The points up to 100 horse-power fall within a reasonable distance of the straight line drawn to represent their average. There are, besides these, two points near the top of the sheet, which should not be considered in drawing the line, because they came from that part of the test (between 8.30 and 9.10) when the mixing valve was accidentally changed. Between these two points and the upper end of the straight line is another group, made up of a considerable number of points, which, without exception, are from the observation taken before 9.15, when the ratio of mixture was 1.11, which, consequently, are not comparable with those points where the mixture was 1.12. The crosses represent the same relation for the brake horse-power, while the hollow circles are the points for the gas per hour against electrical horse-power; and the same general observation may be made for these as for the indicated horse-power line. Three quite important conclusions seem to be warranted by this comparison:

(1) That the proportion of gas to air is a very important factor in fuel economy.

(2) That one test at a light and one test at a heavy load would serve to locate the line, from which a quite approximate prediction

* See discussion of Professor Goss's paper on "Tests of a Ten Horse-power Steam Turbine," by Mr. W. S. Aldrich, vol. xvii., *A. S. M. E. Transactions.*

could be made of the gas consumption under intermediate loads.

(3) That these considerations hold for the fuel consumption per brake horse-power hour and per electrical horse-power hour.

By Fig. 145 is shown the relation between standard gas per

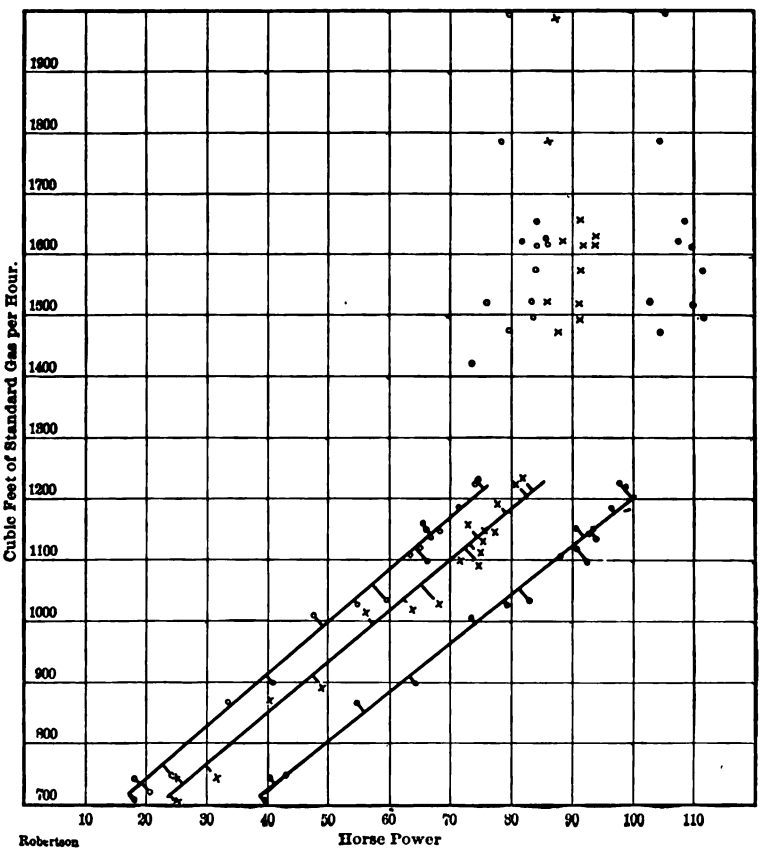


FIG. 144.

indicated horse-power hour and the indicated horse-power based upon observations when the mixture was 1:12. The other curves on this figure show gas consumption per brake horse-power hour and per electrical horse-power hour.

In column 28 is seen the efficiency of mechanism of the plant, found by dividing the output of the generator by the power furnished in the engine cylinder; in other words, the electrical horse-power divided by the indicated horse-power.

Columns 29 and 30 show the British thermal units (B.T.U.) equivalent to the brake horse-power, and the British thermal units equal to the heat value of the gas for a ten-minute period.

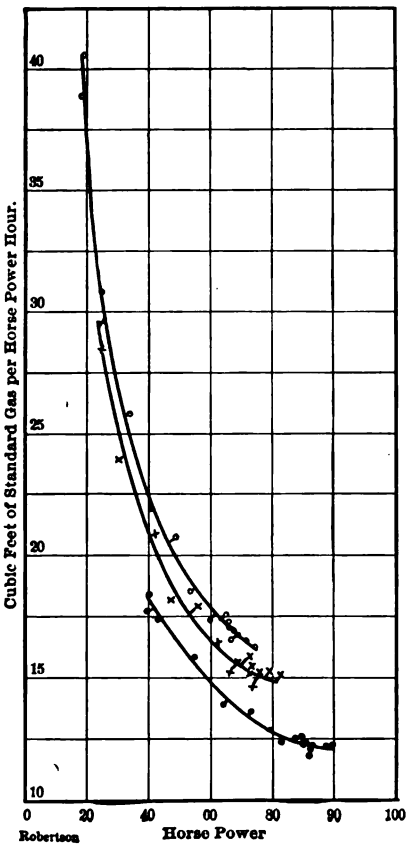


FIG. 145.

Column 31 shows the thermal efficiency of the engine = $\frac{\text{B.T.U. equivalent B.H.P.}}{\text{B.T.U. in gas consumed}}$. The highest efficiency, 17.3 per cent., is seldom equalled in a steam plant; but it is not high for a gas engine. Column 32 exhibits what may be styled the thermal efficiency of the plant. It is the result of dividing the energy of the electrical output by the heat energy in the gas consumed in its production, and gives as a maximum value 15.4 per cent.

The graphical representation (Fig. 140) of Table III. shows at a glance the relation of a number of the various factors. It also shows in a striking manner the effect on the gas consumption when the mixing valve was accidentally changed at about 8.30.

Table I. accounts in a general way for the heat transformation in the engine. The figures are based upon the averages for each hour during the test. The poor showing for the first and second hours was due to the improper ratio in the mixture of gas and air. For the third hour it is to be observed that about one-fifth of the heat energy of the fuel reappeared as work in the cylinder; that about three-tenths was absorbed by the jacket, and that one-half passed out through the exhaust. The item British thermal units per indicated horse-power per minute for the hour is seen to be 204.2, and is of interest for purpose of comparison. The best performance of the test in this regard is at 10.00, when the gas per indicated horse-power per hour was 11.87 cubic feet, giving for the British thermal unit per indicated horse-power per minute, 197.8.

TABLE IV.

RÉSUMÉ OF DATA.

	Average of Test.	Lowest of Test.	Highest of Test.
Indicated horse-power	86.94	37.82	113.05
Brake horse-power (electrical input)	73.26	24.80	93.5
Electrical horse-power	65.51	18.10	86.05
Frictional horse-power	16.88	11.88	20.15
Mechanical efficiency of engine (per cent.)	79.74	62.39	84.62
Mechanical efficiency of plant	70.23	45.4	77.67
Standard gas per indicated horse-power hour	14.18	11.87	18.42
Standard gas per brake horse-power hour	17.96	14.71	29.65
Standard gas per electrical horse-power hour	20.70	16.35	40.59
Thermal efficiency of engine	14.61	8.58	17.30
Thermal efficiency of plant	12.92	6.20	15.40
British thermal units per I. H. P. per minute	.....	197.8	
Exhaust temperature	.....	1048.	1209.

SOME MISCELLANEOUS NOTES.

It should be borne in mind in considering the data here presented that engine No. 1 was the first of this make and size installed for commercial service in this country, and that engine No. 2 (the one tested) was of the same lot of five engines, and was put in a short time after No. 1. Since they were installed, gas enginery has made a considerable advance, and the performance

of this machine is probably not as good as an up-to-date engine would give. It is expected that the engine will be thoroughly overhauled and brought up to date during the coming winter. In case this is done another test will be run in the spring, whence will be possible some interesting comparisons.

Chief among the changes expected to give greater economy will be the substitution of solid oil in the crank case instead of oil and water as at present. It is stated on good authority that the presence of water in the oil when exposed to the conditions met with in the cylinder very much injures its lubricating effect, whence comes rapid wear of cylinders and bearings and, consequently, low mechanical efficiency. Care must be exercised in the amount of oil permitted in the crank case, lest so much reach the cylinders as to carry flame over an exhaust stroke and ignite the next succeeding charge and with it the mixture in the distribution pipe. Any considerable amount of this "back firing" has a very detrimental effect on the engine in general, and seriously interferes with good governing. Back firing may also be caused by a leaky admission valve or a leak in the caging on which the admission valve is seated. (See Fig. 131.)

Cases have been reported where engines are running on gasoline in which a coating of burnt oil has collected on the end of the piston. This, it is thought, may come to high enough a temperature to ignite the incoming charge. At any rate, the "back firing" ceased with its removal.

The red glow of the exhaust pipe at night, or the red-hot condition of the copper ball used in determining the exhaust temperature, bore convincing evidence of the high temperature within the cylinder. This high temperature gives some trouble with the exhaust valves, making it necessary to watch them quite closely lest a little leak soon burns out into a hole of considerable dimension. This intense heat sometimes has caused the breaking off of the exhaust-valve stem. The use of more metal in the valves has practically ended these troubles.

In a gas-engine plant the certainty of action depends upon a number of details, such as quality and time of ignition, proper compression, right proportion of gas to air, control of cylinder temperatures, etc. Any one of these defective to any considerable degree is quite sure to stop or prevent the starting of the engine. In one of the preliminary tests on this engine an observer accidentally struck one of the incandescent lamps in the igniting

circuit. The lamp was apparently uninjured, but the engine at once slowed down. An examination of the lamp showed that just the tip end of the bulb had been broken off, thus destroying the vacuum within and, consequently, the igniting circuit.

On another occasion sand was deposited in the jacket from the cooling water, making it impossible to cool the cylinder properly. The result was that the heat of compression furnished a high enough temperature to ignite the charge, and the engine was run for some time without the igniters in operation.

At various times the gas supply for the city has been shut off. Under such circumstances the engine (acting as a pump) has continued to draw gas from the mains, and to run through such shut-offs of thirty minutes' duration.

Soon after the gasoline vapor generator was installed, artificial gas was piped to the plant, and proved so much more convenient for emergency runs that the vapor generator was not used, and at the present writing has been removed.

In the warm months of summer some trouble has been experienced in cooling the jacket water in the cooling tower. As a result, a motor and pump were installed at the river bank some distance away, and the jacket water secured from that source. As soon as the warm months are over the cooling tower is used again. When the engine was first installed, cast steel gears were used, which, on giving trouble, were replaced by steel cut gears. This change has ended the trouble from that source.

Natural gas is sold to the company by meter at the rate of $.07 per thousand cubic feet.

DISCUSSION.

Prof. R. H. Thurston.—I am particularly interested in this test, as giving unique data relative to gas engines of what we have been accustomed to consider large size; though I presume it will soon be taken to be a very ordinary power.

I observe that the jacket waste gradually works up to 50 per cent. during the trial, and is still rising at its end, while the exhaust waste correspondingly falls off. It would be interesting to know what will become, in time, the normal average waste in jacket water, once the system gets into steady operation. I had anticipated that this waste would be reduced in large sizes; but it does not look like it in this instance. The maximum loss

seems to be here about the usual percentage for small engines, and, rising still, it may prove considerably greater.

The exhaust waste is stated at from 42.7 per cent. to 62.8, and apparently has a maximum in the second hour, a minimum in the fourth. These figures seem to me very high. But they follow the rule that a gain in the exhaust is compensated for by a loss by jacket. The work effect is a maximum at the beginning and a minimum at the end of the trial. Commonly we find jacket waste about 50, exhaust 35, and utilized energy 15 per cent. The thermodynamic efficiency here seems to be 16.04 per cent., a minimum at the end and a maximum, 20.7, at the third hour. The expenditure of heat is a minimum, 204.2 British thermal units, at the third hour; a maximum, 264.7, at the second hour—excellent figures, both. They approximate closely those for our very best classes of steam engine of several times the power of this gas engine. On the other hand, the possibilities of still further thermodynamic gain are indicated by the temperature of the exhaust gases, above 1,000 degrees Fahr., and far above that of the prime steam of our steam engines. Were the steam engine to have its working fluid superheated, and to this exhaust temperature of the gas-engine, it would have a vastly increased thermodynamic efficiency, bringing up its standing from about 20 per cent. to more nearly 25, while, incidentally, it would further gain by suppression of initial condensation, giving probably a total of about 30 per cent., which is still well within the limit of promise of the gas engine, however.

The best work of this gas-engine is given on the log as occurring at 9.15 P.M., with 98 indicated horse-power and 74 electrical horse-power, 82 developed horse-power, and a mechanical efficiency of 76 per cent. for the plant, 84 for the engine, while the thermal efficiency of the plant is 15.4. The best steam engines give about 18 per cent. for the latter quantity, a superiority of about 33 per cent.

The parallel of "Willans' Law" here is interesting, especially when it is noted that there is no "Willans' Law" in a correct sense; the phenomenon being simply that represented by an empirical equation and a curve of which the equation is the algebraic description and definition, and which happens to apply to most forms of throttling non-condensing engines. It is departed from widely in the case of condensing engines, and very observably by some forms of steam engine with detachable valve gear, and it

is not at all true of such condensing engines. The existence of the pseudo-law, however, is an interesting fact to the engineer, and will often prove of great value and convenience through its simplicity as means of computing a probable efficiency of engine at powers other than those for which the constants are obtained by trial. It probably comes mainly from the fact that the internal wastes of the heat engine, by heat exchanges, are usually, in these cases very nearly, though never quite, constant, irrespective of the power developed, as well as of the heat employed in purely thermodynamic transformation. The exhibition of this "law" in this case is a notable and, as it seems to me, important matter.

The statement of gas consumption will have value only when it is known, as here, what a cubic foot of gas weighs at a standard pressure and temperature as measured, and only then. I was recently asked to define this unit, and gave precisely that assumed in this paper: $p = 2{,}116$; $t = 62$ degrees Fahr.

Mr. Edwin Ruud.—Mr. Robertson's test, while very ably and accurately made, may require some comment to prevent a wrong impression as to the economy of the gas engine under question, and I hope that the following remarks may be appropriate:

A practically absolute regularity of motion is an essential feature in an engine driving a dynamo for incandescent lighting. In alternating-current work, especially when two or more units are in parallel, it is of the utmost importance that the motion of the prime movers be steady and alike.

This type of gas-engine was designed and brought out for the purpose of satisfying the demand for a gas motor to drive dynamos for incandescent lighting, and for other exacting work. In order to accomplish this, a system of governing was adopted, in which the explosive charge is graduated to suit the load that the engine may be carrying at any particular period, and hence this engine is operated with a variable compression. The heat efficiency varies to some extent with the changing compression, it being the natural consequence of the resulting changes in the working temperature of the exploding charge in the cylinder. It is true that when a small charge is taken in and exploded, the gases expand to a point closer to that of the atmosphere before they are exhausted, and thus do proportionately more work at the latter end of the stroke; the friction of the engine itself, however, is a source for loss of power, and neither a steam

engine nor a gas engine gives the best efficiency at light loads, as the friction is practically a constant quantity and forms a larger and larger percentage of the power output as the load decreases.

The gas engine tested by Mr. Robertson at the Merchants' Electric Light Association, Lafayette, is rated by the makers at 125 brake horse-power, and has a maximum capacity of 155 brake horse-power with natural gas. The available load in the Lafayette station at the time of the test was, as you have seen from Mr. Robertson's interesting paper, about 80 brake horse-power. This is not very much above half the maximum load of the engine. The accompanying graphic illustration, Fig. 146, shows relation between brake horse-power developed and gas consumed, in cubic feet, by 13 x 14 three-cylinder 125 horse-power Westinghouse gas engines. The upper line is taken from Mr. Robertson's tests, and is carried out to show the estimated consumption to the maximum capacity of the engine. At 125 brake horse-power, or the rated load, the total consumption would be 1,560 cubic feet, or 12.5 cubic feet per brake horse-power.

The next line below (dotted) gives the gas consumption per brake horse-power, which the builders usually guarantee for this size of engine. The lower four lines give the performances of four different engines, taken at random from the record book of tests, the tests being made under normal and commercial conditions. No. 159 was for Bradford Electric Light Company, Bradford, Pa.; Nos. 264 and 267 for Riter & Conley Manufacturing Company, Pittsburg, Pa.; No. 266 for Mesta Machine Company, Homestead, Pa.

The accompanying table is an abbreviated test sheet, showing the actual gas comsumption at respective loads, both total and per brake horse-power hour.

The natural gas used is that furnished to Pittsburg generally, and its calorific value may be put down at 1,000 British thermal units per cubic foot. Numerous tests with the Junker calorimeter confirm this value, although a variation of from 1 per cent. to 3 per cent. is observable from time to time. In the test record, the gas has been reduced to a basis of 62 degrees Fahr. and 30 seconds of mercury.

The efficiency at rated load (125 brake horse-power) of No. 266 at the consumption of 9.2 cubic feet would be $\frac{2,545}{9,200} = 27.6$ per cent.

No. 267, consuming 9.53 cubic feet, would give a thermal efficiency of $\frac{2,545}{9,530} = 26.7$ per cent.

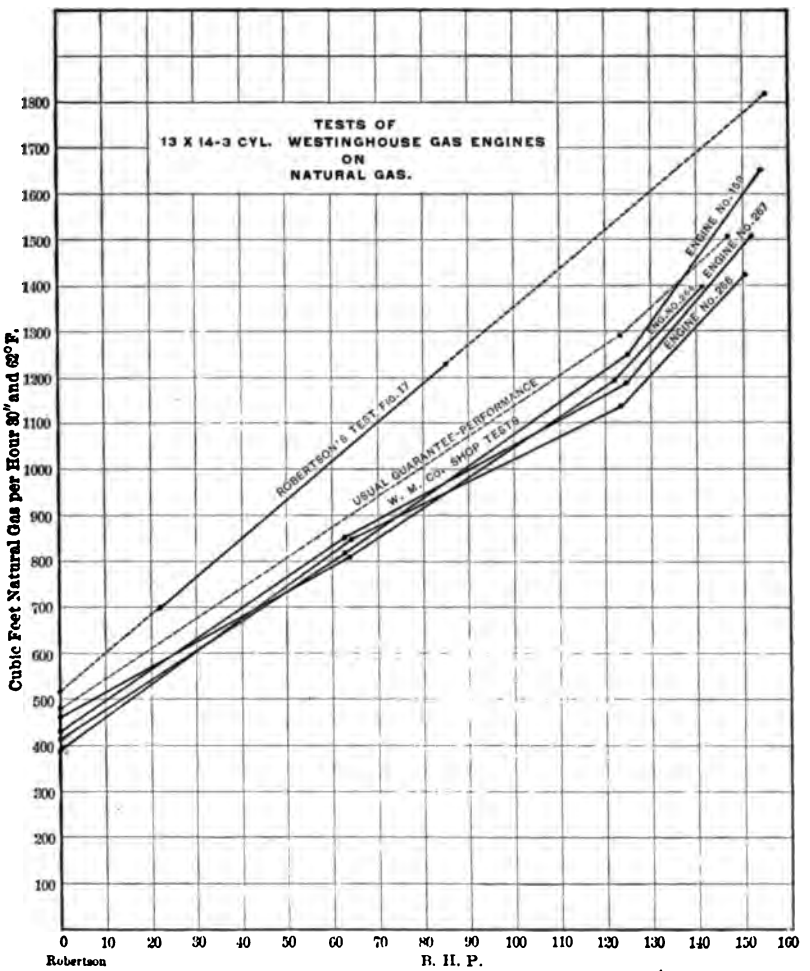


FIG. 146.

No. 264, consuming 9.75 cubic feet per brake horse-power, would give $\frac{2,545}{9,750} = 26.1$; and,

No. 159, consuming 10 cubic feet per brake horse-power hour, would show 25.4 per cent. heat efficiency at the shaft.

Time.	Cu. Ft. per Hour by Meter.	Rev. per Minute.	B. H. P.	Cu. Ft. per B. H. P. Hour by Meter.	Net Brake Load at 33 Ft. Circ.	Remarks.
12 min.	1,420.5	253	150.4	9.4	596 lbs.	13 × 14 (3) No. 266. Test No. 281, July 20, 1899.
10¼ "	1,136	257	123.5	9.2	481 "	
10 "	852	260	64.4	13.2	230 "	
13¼ "	836	267	.....	.....	.....	
15¼ min.	1,506	255	152	9.91	595 lbs.	13 × 14 (3) No. 267. Test No. 283, July 27, 1899.
14½ "	1,188	260	124.7	9.53	481 "	
20.17 "	854	265	63	13.6	248 "	
20.3 "	424	268	.....	.....	.....	
12.58 min.	1,396	248	141.3	9.9	570 lbs.	13 × 14 (3) No. 264. Test No. 280, July 15, 1899.
19.67 "	1,191	254	122	9.75	481 "	
17.33 "	811	258	63.8	12.7	248 "	
27.0 "	455	262	.....	.....	.....	
22.08 min.	1,650	255	154	10.7	604 lbs.	23 × 14 (3) No. 159. Test No. 182, Oct. 29, 1898.
24.25 "	1,250	259	125	10.0	480 "	
18.42 "	820	263	63	13.0	240 "	
118.25 "	411	267	.....	.....	.....	

Mr. C. E. Sargent.—The most interesting result, to me, at least, obtained from the test, is that although this engine is the result of years of experimenting, and was built by a firm whose reputation for good work is world-wide, its efficiency falls far below what we might expect in these days of engineering.

With fuel practically free, this generating plant may be a good financial investment, but if the fuel gas had to be obtained from coal, it is a question if the efficiency would not be less than that of the ordinary compound condensing steam engine, the installation of which from the conditions would seem practicable.

The results obtained no doubt are surprising to many of us who have looked upon the gas engine as a prime mover of nearly twice the efficiency of the most perfect steam engine of to-day, yet the paper shows us just where the losses are, and where improvements may be expected.

If we had a boiler plant with a red-hot smokestack, we would have a good illustration of what we have in this engine, a red-hot exhaust pipe. The products of combustion containing nearly 57 per cent. of the heat units leave the engine as a dead loss.

This waste reminds me of an experiment made a few years ago on a gas engine, which governs in the same manner, and whose cylinder dimensions, diameter, and stroke were practically

of the same ratio as the engine tested. I did not make the test, but was advised by the engineer who did make it that the exhaust from the engine, which was passed through a boiler having sufficient surface to absorb all available heat, generated steam for a steam engine which indicated more horse-power than the gas engine was actually doing when the test was made. I do not vouch for the accuracy of the results of this experiment, but cannot see why such results are not possible under proper, or, rather, improper, conditions.

But to return to results of test under consideration. The terminal pressure from the indicator diagrams shows from 30 pounds to 45 pounds absolute, which in a steam engine would be an excellent argument for compounding, and as the builders of this engine are pioneers in high-speed compound engines, and know its value, may we not expect them to apply their engineering ability in this line to their internal-combustion engines?

One of the most satisfactory conclusions from the performance of this engine is that even with a temperature of from 2,000 to 2,500 degrees Fahr., no trouble is experienced in lubricating the pistons, which is not true of high temperatures in steam engines. Of course, the cylinder walls of a gas engine do not get as hot as the temperature of the burning gases, yet the lubricating oil is next to a temperature which cannot be much less than 2,500 degrees Fahr.

In my own experience the cylinders and pistons of a gas engine are much less liable to cut than in a steam engine, probably because the products of combustion do not condense on the cylinder walls, as they do in a steam engine, and wash the oil away.

I have repeatedly run a double-acting gas engine whose piston was too large for the cylinder, until the piston, expanding more than the cylinder, would bring the engine to a dead stop; and from our experience with steam engines cutting, we would expect to have to drive the piston out, but as soon as the piston and cylinder assumed the same temperature, the piston would be perfectly free and show no signs of cutting.

It would have been interesting to know how the efficiency would be effected by cutting out one or two of the cylinders when the load is light. It always seemed to me that a three-cylinder gas engine had the advantage of being able to give its

maximum efficiency at full, two-thirds and one-third load, though under such conditions the regulation might be seriously impaired.

The fact that an internal-combustion engine with a temperature within which will melt cast iron will do work from dark to daylight-week in, week out, promises much for the future for this type of power generator, and no doubt within a few years we can turn back and read the results of this test and marvel at our extravagance.

Prof. William T. Magruder.—The matter presented in this paper is not only of "timely interest," but should awaken the members of the Society to the recent phenomenal development of gas engines in this country; not only of the small sizes under 25 horse-power, but also of engines of 100 horse-power and 125 horse-power, and more recently of 300 and even 800 actual brake horse-power.

It should be carefully borne in mind that the test reported is of the engine "under service conditions" at only $\frac{3}{4}$ to $\frac{7}{8}$ of its nominal horse-power, and at probably not more than $\frac{1}{2}$ to $\frac{1}{3}$ of its maximum obtainable horse-power, as may be seen by an examination of the indicator diagrams.

Before discussing the paper, may I request that the author will supplement it by additional data concerning the exhaust mufflingchamber, its diameter, depth, and material? Did it contain water, and if so, how much? Was the end of the exhaust pipe submerged, or did it simply enter the cistern at the side or top? Has any data been obtained concerning the latent heat of evaporation of gasoline, as might be done by measuring the "refrigerating effect of the carburetter," or "gasoline vapor generator"? (page 406). The paper states that a wet meter was used; may I ask if it was calibrated before and after the test, and was it found to be satisfactory, and if so, by whom was it made? It was stated that the ratio of gas to air was 1 to 11 and 1 to 12; were any experiments made to test the accuracy of the graduations of the gas and air inlet valve giving the ratio of gas to air? On many gas engines—the Westinghouse may be the exception—the graduations of the inlet valves are very inaccurate, and usually are only intended to be relative. When the ratio of gas to air was 1 to 11, the excess of oxygen was only 23 per cent. Was the area of the indicator diagram described during the exhaust-suction revolution subtracted from the area described during the compression-expansion revolution in ob-

taining the "area, mean effective pressure, and indicated horsepower" of the indicator diagrams?

Experience leads me to doubt the accuracy of the results obtained with the indicator on a gas engine under these conditions, when cards are taken only once every five minutes, and a study of the diagrams presented tends to confirm me.

In line 2, on page 400, the author speaks of "clearance" as being 21 + per cent., and no doubt means the "clearance in per cent. of piston displacement." With steam engines having a clearance volume of from 2½ to even 10 per cent. of the piston displacement, the difference is quite small between the clearance in per cent. of piston displacement and the clearance volume in per cent. of the maximum volume of steam—that is, in per cent. of the sum of the actual clearance volume and the volume of the piston displacement. For example, a clearance of 5 per cent. of the piston displacement corresponds to 4.76 per cent. of the total volume. But the case is quite different with gas-engines. Many of the smaller ones have a clearance which is 30 per cent. to 36 per cent. of the total volume, and corresponding to 42.86 and to 56.25 per cent. of the piston displacement. As there seems to be a tendency to limit the expression "per cent. of clearance," especially among writers on the gas engine, to per cent. of total volume, and to speak of "clearance in per cent. of piston displacement" when that term is intended, I would respectfully suggest that the author insert the phrase "in per cent. of piston displacement" after the word "clearance" on line 2 of page 6.

The heat of combustion to water vapor of the gas as determined from the gas analysis, assuming that by "hydrocarbon" is probably meant benzine, C_6H_6, is found to be 966.39 British thermal units per cubic foot of gas at 32 degrees Fahr. and 29.922 inches of mercury, and to 1012.69 British thermal units per cubic foot of gas if burned to water liquid at 32 degrees Fahr. and 29.922 inches of mercury; or 965.53 and 1009.88 British thermal units per cubic foot of gas burned to water vapor and to water liquid respectively at 62 degrees Fahr. and at a pressure of 29.922 inches of mercury. The author assumes 1,000 British thermal units per cubic foot of gas at 62 degrees Fahr. and 14.7 pounds pressure, which may possibly be near enough for a commercial test, being a difference of 3 + per cent. The author does not give the data wherewith to check the figures given in column 5 of Table I. on "British thermal units absorbed

by the jacket;" but he states that owing to a "breakage of the thermometer used for measuring the final temperature of the jacket water it was necessary to use the temperature from the thermometer in the weighing barrel in its stead." As the percentages of the total heat absorbed by the jacket are quite variable, the difference may be due to the considerable cooling of the jacket water between the cylinders and the weighing barrels, and to the evaporation of the hot water at the barrels. The heat unaccounted for as being converted into work or by the jackets is charged up as "British thermal units exhausted per hour." The amount of heat contained in the exhaust gases at a temperature 1,209 degrees Fahr. at 9.00 P.M., over the temperature, 75 degrees Fahr., of the gas and air at that time, and burning 1,674.88 cubic feet of gas during the second hour, and 11 times as many cubic feet of air, amounts to 467,479 British thermal units exhausted per hour instead of to 1,053,625 British thermal units, or to 27.91 per cent. instead of to 62.80 per cent. of the British thermal units supplied per hour. It hardly seems probable that the difference, or 34.89 per cent., can accurately represent the heat lost by radiation. Possibly this may be explained by our author.

On pages 422 and 423 he speaks of the "thermal efficiencies of the engine and of the plant," meaning the ratio of the energies delivered by the engine and by the electric generator to the thermal energy supplied in the gas. Is it correct to speak of these as thermal transformations or efficiencies? Are they not the actual efficiencies of the engine and of the plant?

Referring now to the indicator cards, may I call attention to the late ignition of the charge in cylinder No. 1, Figs. 141, 142, and 143; that in Fig. 143, although we have what seems to be preignition in cylinder No. 3, and late ignition in cylinder No. 1. Yet with practically the same compression in cylinders Nos. 2 and 3, cylinder No. 2 gives 68.86 feet mean effective pressure, to 59.49 feet from cylinder No. 3, and 50.78 from cylinder No. 2; that owing to the throttling of the inlet charge in Fig. 141, the ignition of the charge in cylinders Nos. 3, 2, and 1 were late, later, latest, respectively; that in Fig. 141 the suction amounts to about 8 feet, which is not an abnormally large figure with a throttling engine; that the maximum pressures are not as high as are obtained at full load; that in Fig. 141 the diagram from cylinder No. 3 would seem to show that owing to the amount of

suction the inlet valve did not close until $\frac{3}{7}$ of the compression stroke had been completed; and lastly, that the exhaust valves of all three cylinders open late, and in the absence of auxiliary exhaust parts, the exhaust line is higher than should be expected.

The gas engine has its peculiarities like other machines, and they must be studied, learned, and provided for. The moral of the trouble experienced with the engine in "one of the preliminary tests" is not to put incandescent lamps in the igniting circuit. What is true of the gas engine is equally true of the electric light as compared with gas light. They all have their special pecularities and points of difference.

Notwithstanding all these irregularities of indicator diagrams, and the almost experimental character of this engine, the test of this engine shows it up in very favorable light as compared with many steam engines, both when compared as to actual thermal efficiency (I. H. P. ÷ G. H. P.), and when compared as to cost of fuel per indicated horse-power hour. The actual thermal efficiencies are given in column 4, Table I., page 15. To make the comparison as to cost of fuel, I would call attention to the fact that the minimum gas consumption was when the engine was running at two-thirds to three-fourths of its nominal horse-power, and 11.87 cubic feet produced 1 indicated horse-power at a cost of .81 mills per hour, and 14.71 cubic feet of gas produced 1 brake horse-power at a cost of 1.03 mills per hour; that the maximum gas consumption reported was with the engine developing one-third its nominal horse power and requiring 18.42 cubic feet of gas to produce 1 indicated horse-power at a cost of 1.29 mills per hour, or 29.65 cubic feet to produce 1 brake horse-power at a cost of 2.08 mills per hour. With large engines at three-fourths to full load, results have been reported, under 10 cubic feet of natural gas, of 1,000 British thermal units calorific value per brake horse-power per hour. So that the results here reported are high rather than low. As it may be claimed that 7 cents per 1,000 cubic feet is below the average, I append a table, giving the equivalent costs of coal per ton used to generate steam to provide indicated horse-power in steam engine, when compared with gas at 1,000 British thermal units calorific value per cubic foot used in this engine and bought for 7 cents, and for 20 cents per 1,000 cubic feet.

EQUIVALENT COST PER TON OF COAL.

When one indicated horse-power hour is developed with	With gas of 1,000 B. T. U. Calorific Value at			
	7 Cents per 1,000 Cu. Ft.		20 Cents per 1,000 Cu. Ft.	
	¼ load.	½ load.	¼ load.	½ load.
1 pound of coal	$1.62	$2.58	$4.63	$7.37
3 pounds of coal	.54	.85	1.54	2.46
5 pounds of coal	.32	.52	.93	1.47
10 pounds of coal	.16	.36	.46	.74

*Mr. C. H. Robertson.**—In the discussion of this paper, one of the unexpected things to the author has been the attention given to the statement of heat account (Table I.). In considering the table it should be borne in mind that the data for the second hour is hardly comparable with that for the other hours on account of the change in the proportion of gas to air. That this had a marked effect on the economy of the engine will be seen by referring to the item British thermal units per indicated horse-power per minute.

In the writer's opinion too much water was used in the jackets —it amounting to an average of 131 pounds per indicated horse-power hour, and having a temperature of but 79 degrees Fahr. when coming from the jacket.

In connection with the remarks of Professor Thurston, comparing the British thermal units per indicated horse-power per minute with the same items for the steam engine, attention may appropriately be called to the best performance of the engine for this test, which was at ten o'clock, and was 197.8 British thermal units per indicated horse-power per minute (Table IV.).

The additional data submitted by Mr. Ruud are particularly timely, as they show what this engine ought to do when in good shape and properly handled. Some such results should be expected from the next test.

Mr. Sargent's remarks, especially concerning the boiler with a gas engine for a furnace, have been of interest to us all, though it seems hardly correct to say that "the products of combustion containing nearly 57 per cent. of the heat units leave the

* Author's closure, under the Rules.

engine as a dead loss—hardly correct in the sense that the engine could not lose what from the nature of things never was available for its use.

The exhaust muffling chambers were made by cutting in two an old cylindrical boiler and burying the halves open end downward. Into these "cisterns" the exhaust was discharged, from whence it escaped through a tile at the top. The size of each cistern is approximately 4 feet in diameter and 6 feet deep. The meter used in the tests was one of 5,000 cubic feet per hour capacity, and carries the trade name of the Westinghouse Gas and Fuel Manufacturing Company. The fluid used in sealing the compartments is a special non-evaporative oil. The meter once adjusted, and with the oil kept at a proper height, is an instrument of precision. Its readings were taken as correct.

So far as the author is aware no experiments have been made at this plant to determine the latent heat of evaporation of gasoline.

No experiments were made to determine the correctness of the ratio of gas to air as shown by the mixing valve, the setting of the two halves of the valve being such as from a previous experiment had been determined to be most economical. This was done by putting the engine under a constant load, and then, with the gas valve in a given position, changing the air valve until the gas consumed in a given time was a minimum. While it is true that the mixing valves on some gas engines are roughly made, it is not true of the engine here considered. The proportioning of the mixing valves represents the most careful machine work of the whole engine.

In taking indicator cards the pencil was held on for three explosions. In working them up all three cards were planimetered, and the average area used in determining the mean effective pressure. It is believed that the results are practically correct.

Concerning the suggestion that there might have been considerable error in taking the temperature of the jacket water in the cooling barrel, because of the breakage of the thermometer at the jacket, it may be said that the temperature of the water in the barrel was 79 degrees, and that the temperature of the room was about 73 degrees. Under these conditions it is not probable that there was much drop in temperature in passing from the engine to the weighing barrel.

The author prefers to base the figures for the heat exhausted

during the second hour upon the methods indicated in the paper rather than upon calculations involving the temperatures and specific heats of the exhaust gases. In case such a calculation is attempted it would not seem correct to assume that the ratio of gas to air was 1.11, when the fact that this was not so has been pointed out so many times in the paper.

In regard to the remarks about clearance per cent., about manner of planimetering cards, and about thermal efficiency, it is believed that the methods used, and the interpretations given, are the same as those practised by our leading engineers and technical educators. It is, therefore, not deemed wise to make the changes of wording suggested.

At an early date it is expected that more complete data will be presented, representing the results of tests now in preparation.

No. 844.*

HIGH HYDROSTATIC PRESSURES AND THEIR APPLICATION TO COMPRESSING LIQUIDS, A NEW FORM OF PRESSURE GAUGE.

BY FRANCIS H. STILLMAN, NEW YORK, N. Y.
(Member of the Society.)

LAST year there was supplied to the West Virginia Agricultural Experiment Station a small press for some test work which they desired to do, in determining the effect of high pressures upon the bacteria which appear in milk. Mr. B. H. Hite, the chemist at the station, as a result of their experiment, has published in the *American Chemical Journal*, of July, 1899, an article upon the method for carrying out chemical reactions under high pressure, and the station has issued a bulletin (No. 58, June, 1899) giving the results of the milk experiments. These papers referred to pressures which I questioned (as high pressures are frequently incorrectly reported), and in reply I received a letter from Mr. Hite, in which he stated that he "had repeatedly had pressures of 45 tons upon a piston one-half inch in diameter." This corresponds to over 450,000 pounds per square inch; no allowance being made for the loss in frictions of packings and parts. In reply to a letter asking the privilege of submitting his experiments to the American Society of Mechanical Engineers, Mr. Hite has sent me an article so much more interesting that I take pleasure in presenting almost the entire matter sent to me, adding some items from the above-mentioned articles.

The paper is practically divided into three headings:

1st. The method and device used in subjecting liquids to high pressure.

2d. The method and apparatus used in measuring the compressibility of liquids under such pressures.

3d. The application of the last method to the measurement of the pressures themselves or *a new pressure gauge.*

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions.*

In order to subject a liquid to pressure, the capacity of the vessel containing the liquid must be decreased. This suggests at once a cylinder and piston, but no simple cylinder and piston will hold a liquid under very high pressure, for no matter how well the piston may be ground to fit the cylinder a high pressure will expand the cylinder (not to say contract the piston), thus leaving a space between them through which the liquid will escape. It seems to be practically impossible to obtain such contact between the packing and the piston and cylinder that a liquid under high pressure will not force its way out. Indeed, about the only contact that is equal to such cases is that between the particles of one continuous piece of metal, from which it would appear that in order to secure the highest pressures the end of the piston and walls of the cylinder would have to be one solid piece for all positions of the piston; or that the liquid would have to be completely encased in one unbroken piece of metal. If these conditions could be realized, the pressures obtainable would be limited only by the strength of the materials (*e.g.*, steel) used in the construction of the cylinder. A description of such a method follows:

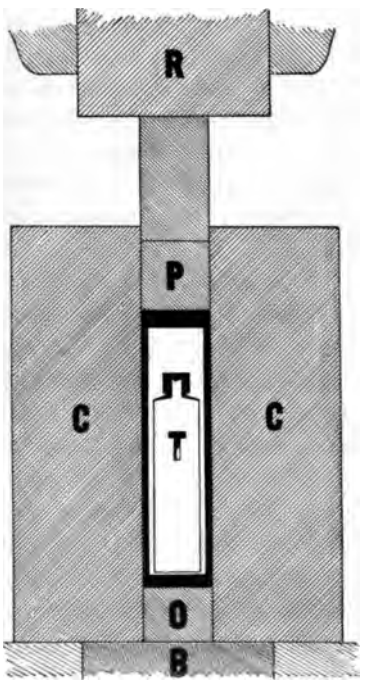


FIG. 147.

The liquid to be subjected to pressure is placed in a lead tube. In working with liquids that would attack the lead (*e.g.*, strong acids) these may be placed in the screw cap collapsible platinum tube *T* (Fig. 147), which is closed with a lid of the same material and placed in a heavy steel cylinder *C C* (Fig. 147). The lower end of the cylinder being closed with an accurately fitting steel plug *O*, the upper end with the piston *P*, the pressure is applied to the lead tube and the liquid within it by means of a hydraulic machine as shown in Fig. 148.

The lead cylinders are placed inside of a steel cylinder, such as shown in Fig. 149, in which the black square represents a solid

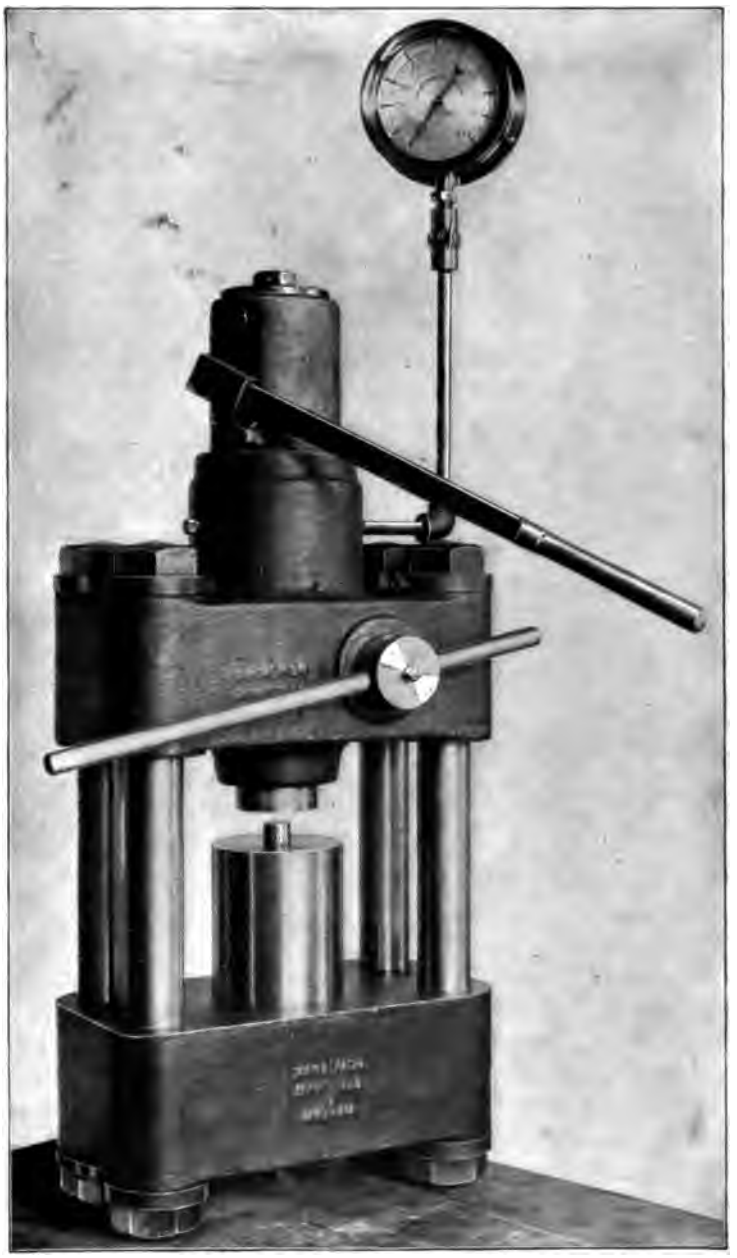


FIG. 148.

block of lead, resting upon a narrow shoulder, and upon this rests a piston which is supported from side spring by a following screw designed to hold the pressure when once obtained, if so desired, and in the experiment they were so held for hours at a time. The pressure applied by the press upon the piston forces the lead down into the cylinder (as indicated by the dotted lines), thus packing it successfully. The piston must fit the cylinder accurately and smoothly, otherwise the lead (not the liquid) will leak out around it. The cylinders used were five inches in diameter and seven inches long. The inside diameter varied from one-half inch to an inch and a quarter. With such cylinders the following pressures may be obtained:

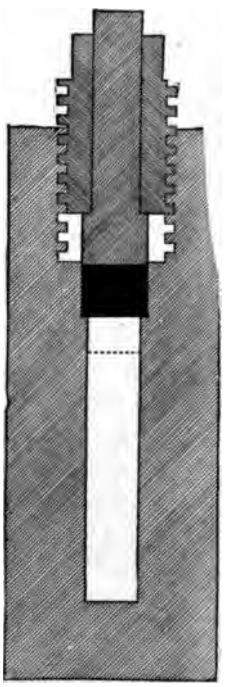


FIG. 149.

1¼	inches	in	diameter	....	100,000 lbs.	to 150,000 lbs.
1	inch	"	"	....	100,000 "	" 200,000 "
⅝	"	"	"	....	200,000 "	" 300,000 "
½	"	"	"	....	300,000 "	" 400,000 "

Most of these cylinders have been forced to higher pressures, but always with more or less injury to them.

Most of them were made of one piece of tool steel, although quite a number of them were built up of concentric pieces shrunk together. The best results were obtained with cylinders made by Brown & Sharpe, of one piece of special tool steel from the Howe-Brown Co., which, without much tempering, was hard enough to keep its shape; but no matter how hard the material may be, the cylinder will yield more or less under high pressures, and for this reason it is better to make the plug O and the lower piece of the piston P of softer steel, so that under the pressure these may also spread. This was found to be absolutely necessary in working with the half-inch cylinder under the higher pressures named. Indeed, with this arrangement, even higher pressures than those above given have been obtained; but in these tests the cylinders suffered considerable injury.

It will be observed that it *is the continuous lead packing that is responsible for the high pressures obtainable with this device*, and

it should be stated that, no matter how high the pressure may be, there *is never even so much as a trace of a leak* while the pressure is being applied. On removing the pressure the liquid, in expanding to its original volume, will often loosen the lid of the lead tube; and in case very high pressures have been used, the lead tube, in stretching to its original capacity, will often be pulled completely in two. Liquids are by no means "practically incompressible" when they get in this machine. The expansion on relieving the pressure is very apparent, and so great that you could measure it with a rule. Even in working with some of the lower pressures a column of water five inches long will expand a half inch or more.

The compressibility of liquids may, under these high pressures, be very accurately determined in the following manner:

The little pycnometer bottle (shown in the middle of Fig. 150, and differing from an ordinary glass-stoppered bottle only in that the top of the stopper is expanded into a little bowl or cup which, when the stopper is in position, communicates with the interior of the bottle by means of a very fine capillary hole through the stopper) is weighed accurately, empty, then weighed full of mercury, which, of course, gives the weight of the volume of mercury necessary to fill the bottle. The mercury is then poured out and the bottle filled with the liquid whose compressibility is to be determined, the stopper inserted firmly, and a quantity of mercury poured into the little cup. Although the mercury is much heavier, of course, than the liquid (for example, water) in the bottle, the mercury cannot enter the bottle, because the water and mercury cannot pass each other in the capillary hole. Any difference in pressure, however, will allow either the mercury to flow into the bottle, or the liquid within the bottle to flow out, depending upon whether the pressure is higher without or within the bottle. The little bottle loaded in this way (with mercury in the cup, and the liquid whose compressibility is to be determined in the bottle) is placed in the lead tube, which is then filled up with water and subjected to pressure in the usual way, when just enough mercury will enter the bottle (and fall to the bottom) to make up for the compression experienced by the liquid (water) in the bottle under the pressure applied. On removing the pressure a quantity of the liquid (not the mercury) will be forced out through the stopper; but this does not matter, as everything is estimated in terms of the mercury, which is then poured out, dried, and

weighed, and from the weight of this quantity of mercury and the weight of the quantity required to fill the bottle the compressibility of the water liquid is estimated. This, of course, neglects the compressibility of the small quantity of mercury that found its way into the bottle while the pressure was being applied. This will have to be estimated in a special determination in which a slightly different bottle is used. For this determination the top of the stopper need not be expanded into a cup, but the lower end of the stopper must extend some distance into the bottle, which is simply filled with mercury and weighed (the weight of the bottle having been determined), placed in the lead tube, which is filled up with water and subjected to pressure as above. In this case the water from around the bottle enters the bottle to take the place of any contraction experienced by the mercury, but, being lighter than the mercury, rises to the top (above the lower end of the stopper); and so it is a corresponding quantity of the mercury that escapes through the stopper when the pressure is removed. By weighing the mercury left in the bottle and comparing this weight with the weight of the mercury required to fill the bottle, the compressibility of the mercury under the pressure used can be determined. In this case, of course, we neglect the compressibility of the small quantity of water which entered the bottle while the pressure was being applied; but from this determination and the one mentioned above (compressibility of water), the compressibility of both the water and the mercury may be calculated.

In this way the compressibility of a number of liquids at a number of different pressures has been determined, and the compressibility of liquids containing known quantities of various substances in solution has received quite a little attention, as the results are of considerable interest from a chemical standpoint; but these latter results, however, would probably not be of so much interest to mechanical engineers. Since water and alcohol are used so extensively in hydraulic machinery, you might care to know that under a pressure of about 65,000 pounds to the square inch water is compressed over 10 per cent., and alcohol more than 15 per cent.

As I was very anxious to determine with great accuracy the difference in the compressibility of a pure liquid and that of the same liquid containing some substance in solution, and as slight errors would, of course, be introduced by the friction of the

piston and by possible slight inaccuracies in the reading of the gauge, the compressibility of the pure liquid and the solution were determined at the same time; that is, two bottles were placed in the lead tube at the same time, when, of course, they were subjected to the same conditions. Working in this way, of course the bottle containing the pure liquid simply serves as a pressure gauge, but the results obtained in this way were so much more satisfactory that I am led to suggest one of these little bottles as

A Perfect Pressure Gauge.

By means of these little pycnometer bottles, as shown above, the compressibility of the liquid may be determined under any pressure up to that of the crushing strength of steel, and having determined, once for all, the compressibility of mercury and of some other liquid, preferably water, this method can be used to determine with great accuracy the pressure on the liquids in hydraulic machinery, etc.

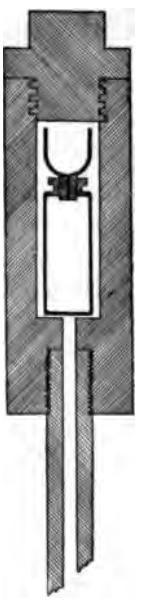


Fig. 150.

It would only be necessary to load one of these little bottles with water and mercury, as described, and place it in a tube communicating with the liquid in the hydraulic machine, say in some such arrangement as that shown in Fig. 150. The accuracy of pressure gauges necessarily depends upon the elasticity of some material. Those in general use depend upon the elasticity of some solid. Solids are never perfectly elastic, even when subjected to relatively small strains, and the change in form which they experience as the result of pressure must be greatly magnified in order to make the gauges in which they are used sufficiently delicate; and even then such gauges have but a very limited range. But such difficulties are only too well known.

In this proposed gauge the accuracy depends solely upon the elasticity of the water and mercury and the balance used in the weighings, and liquids are perfectly elastic; and the analytical balance has reached about as high a degree of perfection as any instrument known to science. The accuracy or delicacy of this gauge hinges upon determining volumes by weighing mercury, and

there is hardly a determination known to science which can be made with greater accuracy. The quantities of mercury to be weighed would, of course, depend upon the size of the bottle used; but even when working with a bottle two inches long by three-fourths of an inch in diameter, the quantities of mercury are sufficient to enable a reasonably good balance to detect differences in pressure of *a pound throughout the range of the several hundred thousand pounds mentioned.* A gauge which would measure pressures as great as this, throughout anything like such a range, would, so far as I know, be regarded as a jewel indeed; and I can't help thinking that such a gauge as the one proposed should be of more than ordinary interest to mechanical engineers; everything connected with it is so simple, and it would be such an easy matter to construct it and attach it to any hydraulic machine. It might even be used in other lines of work if placed in a lead tube and cylinder (such as above described) with a piston of definite area.

DISCUSSION.

Mr. A. F. Nagle.—The scientific precision with which this paper has been prepared would make it appear as hypercritical to criticise it at all, but I will venture to call the author's attention to the omission of any reference to the presence of air in the liquid (water) used in this gauge. We have been educated to the belief that liquids were absolutely incompressible, and that such compression as may be observed was due to the presence of air and a vapor of its own temperature and pressure. We have also been taught that the volume of air held in solution by liquids is directly proportional to the pressure under which they exist. In illustration of the latter law we know that in the vast majority of air pumps in our condensing engines the air is removed solely by its solution, or mixture, with the water, and unless the last-named theory were correct, air would not be removed at all from condensers. It is true that other and better forms of condensers remove the air and vapor from above the water, but until recently the former practice has prevailed.

Another practical illustration of the presence of air in water and liquids is found in the practice of fruit and meat preserving businesses, where the contents are always heated to a boiling temperature to expel the air.

I have frequently desired to know the amount of air present

in water, and the best information I have been able to obtain is that falling water will contain about 6 per cent. of its own volume of air. I know, however, of no experiments to prove this statement.

With these theories and facts in mind I am somewhat surprised to find no reference to the presence of air as effecting the results of the experiments with this pressure gauge, and I should be pleased to hear from the author how he regards this phase of the subject.

Professor Jacobus.—As I understand it, the pressures on page 442 are calculated from the forces exerted on the plugs. The friction of the plug affects the results considerably. We have used paraffin in the same way as lead is used here for producing comparatively light pressures, the highest which we obtained being about 30,000 pounds per square inch. The pressures computed from the force exerted on the plug were compared with the pressures as measured by a device which I described at the Hartford meeting two years ago, in which a rotating plug is used so as to eliminate the effect of friction. It was found that even with paraffin there was considerable friction, amounting to about 10 per cent. at pressures of 15,000 pounds per square inch or less. With lead it is probable that the friction will be much more than with paraffin, so that it is hard to say how great an error there is in the results given in the paper.

It also appears that the pressure exerted on the plugs may have been estimated from the pressure on the piston of the hydraulic press represented in Fig. 148 of the paper. If this was the case, and no allowance was made for friction in the hydraulic press, there would be an additional error in the same direction as the error produced through the friction of the plugs, and both would tend to give too high results for the pressures which were obtained.

It is stated that no simple cylinder and piston will hold a liquid under very high pressure, no matter how well the piston may be ground to fit the cylinder. This is true if there is to be absolutely no leakage, but a comparatively tight joint can be obtained with a piston of a small diameter, say one-eighth of an inch, which is acted on by oil of a viscous nature. In tests which we made some time ago to determine the bursting strength of samples of Mannesmann's steel tubing, a small plug of this class was employed in measuring pressures as high as 25,000 pounds per square inch. In

these tests the pressure was produced by means of a piston which passed through a packing of bronze, the form of which is shown in cross-section in Fig. 151. This packing acted on the principle of a cupped-leather packing, that is, it made a tighter joint as the pressure increased. With this arrangement there was practically no leakage, and the pressures, as has already been stated, were as high as 25,000 pounds per square inch.

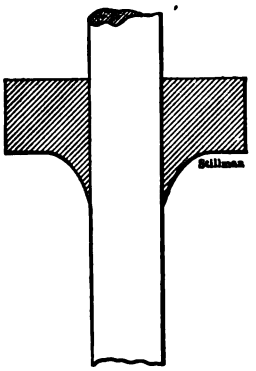


FIG. 151.

It appears to me that a rotating plug of small diameter acted on by an oil pressure might be employed, with advantage, to calibrate the readings obtained with the lead plug device described in the paper. These calibrations would, of course, have to be made at comparatively low pressures up to, say, 50,000 or 100,000 pounds per square inch, but if a law could be obtained at the lower pressures it could be applied in estimating the higher pressures.

I think that probably Mr. Hite has taken care there was no air in the water, because in physical work the air is taken out of the water by reboiling in all cases where the density is an important feature. For measurements of a refined character the middle third of the water evaporated in the still is retained, and the first and last third discarded; and this middle third is reboiled to eliminate the air.

Mr. Gus C. Henning.—It does not appear to me that certain statements of the paper, made upon the strength of Mr. Hite's investigations, should be allowed to go unchallenged. Fig. 148 in the paper, which shows the apparatus used in these tests, presents the main piston just above the lead plug, and above the guide lever, without support, so that it is unconstrained against lateral bulging. We have no records of any metal which show it able to resist, without yielding or crushing, loads of the magnitude which are reported in the paper. I have never known of any modern tool still to show a safe working stress under such conditions as indicated. It implies that the material used in these small piston rods had a yield point much above 450,000 pounds per square inch.

I think, however, that the experiment used to show actual com-

pression of water should be examined more closely. The flask of elastic or flexible material, such as glass or platinum, is filled with liquid; the stopper is then inserted, but it is perforated by a capillary hole. The flask is then placed in a steel cylinder, which is then filled with water around the flask, and mercury is placed in the cup-shaped stopper.

It would appear to me that when the glass vessel is filled with the liquid under atmospheric pressure, it would reasonably be supposed that it underwent certain elastic deformations. Under pressure of the liquid outside of the flask these deformations would disappear, but would reëstablish themselves when the flask was again released after being exposed to pressure.

In this view it would seem to me unsafe to infer too much from the behavior of the mercury in the orifice, and I think, therefore, that it would be safe to wait before we abandon our previous opinions as to the compressibility of water, until we are sure that the occasion of the phenomena observed is not the deformations of the vessels used to contain the liquid undergoing experiment.

The advisability or practicability of using a pycnometer as a perfect pressure-gauge would appear to me to be questionable. The calibration of such a piece of apparatus would require a closeness of reading or weighing which is usually beyond the ability of most users of analytical balances. It seems to me that the accuracy obtainable by such a "perfect pressure gauge" has been overstated in the paper. I think, furthermore, that scales of such accuracy as would seem to be called for are scarcely appropriate apparatus for shops or factories, and that such gauges—dependent upon such balances—could not be serviceable where frequent determinations of pressure were to be made.

*Mr. F. H. Stillman.**—I regret that it did not occur to me to state that the water used in the compressibility tests had been distilled, boiled for three or four hours, and redistilled.

The point raised by Professor Jacobus in regard to friction in the press and in the plugs in the cylinder is well taken. The pressures were simply calculated from the diameter of the pistons and the readings of the gauge shown in Fig. 148. The figures reported, however, were round numbers, which I am inclined to think leave a margin sufficient to cover the effect of friction.

In some of the earlier tests with high pressures a film of lead

* Presented at author's closure on behalf of Prof. B. H. Hite.

from the lead tube (indicated in section, Fig. 147, by the heavy line surrounding the platinum tube T) would force itself up around the piston P, and doubtless increased the friction very materially, but this was overcome by making the lower part of the piston P of softer steel, as stated, and by inserting a plate of some harder metal than lead between the lid of the lead tube and the lower end of the piston. In order to further decrease the friction the upper piece of the piston P (Fig. 147), was always made of tool steel tempered hard, and of about a sixty-fourth of an inch smaller diameter than the cylinder, yet under the highest pressures given this piece would often split in a straight line along one side, and doubtless expanded laterally until it filled the cylinder. In these highest tests the length of the lead tube was always so selected that at the maximum pressure not more than three-eighths of an inch of the piston extended beyond the top of the cylinder, and for fully one-third of this distance the piston would be embedded in a soft steel plate used to protect the ram of the press.

The error due to friction was eliminated from some of the tests with pressures of ten tons and under by attaching a gauge directly to the cylinder shown in Fig. 140, but here I encountered evidence of irregularities in the readings of the gauge. In these tests, two pycnometer bottles (of different capacities) were placed in the cylinder at the same time (when, of course, they were subjected to like conditions of temperature as well as pressure), and although these would check each other to the hundredth part of one per cent., they would not always give the same figure for the same pressure as indicated by the gauge. It was this that led me to suggest the use of these pycnometer bottles in measuring pressures, and within the next two months it is my intention to work out the compression curves referred to for water and mercury, using a testing machine to furnish and measure the pressures, and with the lower pressures, at least, I hope to be able to use the very happy suggestion of Professor Jacobus in regard to a "rotating plug acted on by an oil pressure."

No. 845.*

THE MECHANICAL EQUIPMENT OF THE NEW SOUTH STATION, BOSTON, MASS.

BY WALTER C. KERR, NEW YORK, N. Y.

(Member of the Society.)

Assisted by HENRY J. CONANT, WILLIAM W. CHURCHILL, FRANCIS BLOSSOM, J. P. COLEMAN, AND CALVERT TOWNLEY.

THE terminal station of a railway system comprises essentially the approaches, yards, and side tracks, the train shed with its stub tracks, the head house—usually in the form of an open quadrangle around three sides of the train shed—and the engineering appliances which are required to serve the property and its tenants. It is primarily of these engineering appliances in connection with the Boston South Station that this article treats. It has been thought proper to have the various sections described by those who principally designed them, or who have been intimately connected with the work and who should therefore be regarded more as having created this mechanical engineering plant than as merely assisting the contributor in the preparation of this paper.

The requirements being somewhat miscellaneous and not so easily identified as those of the large structures such as train shed and head house, were left somewhat longer undetermined than the former. The trustees realizing, from long personal experience, the difficulties surrounding the division of such work among many contractors, sought for a concern who should be both engineers and contractors and who had facilities for expeditiously designing and executing all of the work required, notwithstanding it was of such a nature as would ordinarily be much subdivided.

In the search for an organization capable of undertaking the entire work, a choice was made of the Westinghouse interests, and

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

brief negotiations with Westinghouse, Church, Kerr & Co. led to an agreement by which the latter was given access to such information as was on hand and full opportunity to acquire or create the requisite data, upon same to completely design and specify all of the engineering work required to properly serve such a terminal, and to submit bids for the construction of the work prior to the admission of others to like privileges. This agreement was faithfully and literally kept by the trustees and their representatives notwithstanding the urgent pressure brought from many sources demanding data on which to figure upon all or part of the work.

The design of this plant involved more than ordinary engineering complication because of the peculiar situation of the terminal within 90 feet of tide water, in a very open soil full of old docks and timber cribs, with some portions more than 8 feet below extreme high water; also the peculiar shape and exposure of buildings, together with the climate of Boston and the occupancy of the premises by various roads.

The work was at once taken in hand and an engineering corps formed within the Westinghouse interests to handle it. It would be quite improbable that any one engineering office would have at its command all of the talent of the various kinds required for performing engineering work over so broad a range, and only in an association of diversified interests, in which manufacturing and engineering extend over a wide field, could a corps of engineers be instantly organized, the work put in hand without delay, without experiment as to the fitness of men and without question as to the harmony of their coöperation. Very few engineers appreciate of just what such work chiefly consists. It being generally presumed that this was largely an electric installation, there was a natural inclination to treat it as an electric problem. Those more intimately connected with such work would, however, realize that the electrical part is, on the whole, small relatively to other divi sions and in point of expenditure is a comparatively minor portion of the plant. In fact, no one section predominates conspicuously unless, possibly, the interlocking switch and signalling system.

It was realized that the first requisite in undertaking the design of this work was quick determination of what it should comprise, for the time being short, it could not be done many times over in the light of growing knowledge obtained from continued redesigning. The first step, therefore, after carefully contemplating the

FIG. 154.—VIEW OF YARD TAKEN FROM BENEATH TRAIN SHED, AFTER BLIZZARD OF FEBRUARY, 1899. STATION HAD BUT JUST BEEN PUT IN OPERATION.

probable requirements, was to despatch men to all of the principal terminals of the country to collect data as to the requirements of such terminals, the ways in which they had been best filled, and especially of the features, which had been incorporated, that were in use found inadequate or disadvantageous. A couple of weeks of such investigation brought these various engineers together in Boston with their associates, who had meanwhile been mapping out general plans of operation and getting ready foundation drawings of the property, train shed, power-house site, head house, and determining levels and various quantities. The corps in all comprised some fifteen men, in addition to which S. Homer Woodbridge, heating and ventilating engineer of Boston, was retained as consulting engineer to assist in the design of the heating and ventilating plant. The work then definitely started, and within 90 days from the time that it was first contemplated, the designs were finished.

In addition to the detailed specifications, there were prepared a series of monographs on each important section of the work, giving the reasons for the methods adopted and involving considerable of the data on which the work was based. These discussions contained much regarding methods or apparatus considered but discarded, as well as those adopted, and the monographs were used largely in lieu of the specifications in the consideration of the matter by the board. Complete estimates were also made and the plans and specifications were accompanied by a proposal to construct the entire plant.

The plans and specifications were subjected to the most searching scrutiny and criticism. The writer was chosen to present the matter in the interest of the various Westinghouse concerns represented in the design, and after it had been fully laid before the board and had met their general approval, a board of engineers was convened, comprising the chief engineers of the four tenant railroads and certain others connected with said roads in managerial capacities, together with the resident engineer of the Boston Terminal and Dr. E. D. Leavitt, of Cambridgeport, Mass. The designs were laid before this board, the specifications read, monographs considered and alternate methods discussed. After many sittings, the plans and specifications were approved in substantially their original form, except as to such modifications as had meanwhile become necessary, due to other changes in the station design.

The plans and specifications then going back to the board with the engineers' unanimous approval, the negotiations turned to the financial side, under the inconvenience which often attends the presence of only a single bid and requiring justification of the price. This necessitated investigation of the cost of engineering work of other terminals, and a satisfactory demonstration that the plant could be built for, and was worth, the price asked. It was shown that by the method in which this work was taken up, designed and to be executed as one complete undertaking, The Boston Terminal Company was securing an advantage of about $100,000 over the fair *pro rata* price which it should have cost when judged by the contract prices paid to various contractors in other terminals, a substantial portion of this gain being represented by the economies possible where work is thus designed and executed by one organization experienced in all the work undertaken.

Due consideration was given to the relative merits of the several ways in which so diversified a plant might be installed. The conditions were such that the advantages of having the work done, and the operative results assured, by one contractor were considerable. The trustees, however, could not justify an award without competition except on terms proposed by them, the nature of which fully protected the interests of The Boston Terminal Company, assured to it the greatest value for the expenditure involved, and warranted their unanimous action in placing the contract for the entire work of construction in the hands of the engineers who designed it.

As this engineering work approached completion, an operating force was organized chiefly from men who had worked on the erection in various departments, the entire plant subsequently put in commercial operation, logs prepared and daily records kept, and all necessary details perfected. The plant, therefore, was not merely made ready for use, but was put in operation with a completely organized force so that it could be assumed by The Boston Terminal Company with the least risk.

Many instances might be cited to indicate the quality of the design and construction of the engineering work of this terminal, but none could be more significant than the record of operation on first starting. It will be generally admitted, when a large and more or less complicated plant, involving many functions, is first put into operation with the various parts interdependent

upon each other, that the first few weeks form a critical time during which many shortcomings may be properly forgiven. In this instance, however, the whole plant was put in operation in the dead of winter, and Boston was immediately snowbound; the temperature dropped below zero, putting every section, from the switch and signalling apparatus to the leader-thawing devices, into emergency service. The result can be stated almost without words. Nothing happened. The plant operated day after day without apparent relation to the hard service imposed. Nothing failed, not even so much as a joint in all of the many miles of piping connected with the hot-water heating apparatus, notwithstanding the fact that a large portion of this pipe was temporarily supported in mid-air in permanent position through the site of the express buildings, which were not then erected. (See Fig. 193.)

All of the conditions surrounding this engineering work, from its first inception to the placing of the last portion in position, were all conducive to the obtaining of the best results at the lowest cost. The patience of the board of trustees, in understanding the detail of the work, was unusual; the earnest coöperation of the resident engineer and the hearty good-will which surrounded this entire work, contributed not a little to the results secured.

It will be noted that this engineering work was conducted on a basis which is growing more prevalent, of entrusting the work of engineering design and contract for construction to the same engineers. This custom seems to have obtained more in mechanical than in any other form of engineering, due, perhaps, to the fact that mechanical engineers and mechanical engineering contractors are more nearly the same type of men than civil engineers and most civil engineering contractors; or architects and most builders. Another reason may be that mechanical engineering developed into large proportions long subsequent to other forms of engineering, also subsequent to the opportunities for educational advantages and is closely linked with manufacturing processes. It has thus, for reasons not altogether easy to analyze, become the custom for mechanical engineers to associate themselves with manufacturing or contracting corporations.

The growing tendency of purchasers to concentrate the responsibility of design and construction, has further led to the placing of large engineering work in the hands of contractors who first design and then construct to their own designs and specifications. Whatever be the technical objections to this method of conduct-

ing work, or whatever arguments may be urged against its theoretical feasibility, there seems to be no doubt as to the good results of its practice and the conduction of much work in this line has led the writer to believe that it is one of the best methods yet adopted. There seems to be no incompatibility of relationships and the universal satisfaction which it has yielded warrants a fair word in its favor. It should, however, be understood that the fact that an engineering concern is so situated as to be able to do such work, in no wise incapacitates it for conducting contracting along the usual lines of bidding to the plans and specifications of others. It may not be too broad a statement that many classes of engineering design gain little from so-called disinterestedness, but gain much from a certain balance and gravity which follow only from the close touch of personal experience, and from the realization that the designer must responsibly execute his design within fixed commercial limitations. In other words, a strong guarantee of accuracy and quality results from concentrated interested responsibility. To moralize slightly further, the virtues of competition are not always realizable in certain classes of work, and such work as is here described is peculiarly the type which, for the production of the best results, requires a closer intimacy than would ever be gained through the natural channels of competition, and contributes to results of an order not usually possible. This may not be engineering, but it is very near it.

In the division of work, the contributor of this article undertook the general management and presentation, giving more or less attention to all sections. The entire undertaking was put in responsible charge of Mr. Henry J. Conant, then manager of the Boston office of Westinghouse, Church, Kerr & Co., who prepared specifications and who afterwards had charge of the detail designing and execution of the work, etc., while the general design and coördinating of the various designs for different sections was in the hands of Mr. W. W. Churchill, mechanical engineer of Westinghouse, Church, Kerr & Co., who was assisted in this by Mr. Conant, and who also assisted in preparing specifications and in the execution of the work. The switch and signal work was designed entirely by the Union Switch & Signal Co., of Pittsburg, one of the affiliated Westinghouse interests; this work being conducted by Mr. E. H. Goodman. The electrical work was designed through the association of the Westinghouse Electrical &

Manufacturing Co., and more immediately by its Mr. Fowler. The ice and refrigerating plant was designed by Mr. Francis Blossom, in charge of the ice and refrigerating department of Westinghouse, Church, Kerr & Co., while the Westinghouse Air Brake Co. contributed to the air-brake testing outfit.

The Problem.

Most of the historical facts here presented were obtained through the courtesy of Mr. George B. Francis, the resident engineer of The Boston Terminal Company, to whom it is desired to extend thanks for the assistance which he has thus rendered.

Some time early in January, 1896, the project for a union station for the use of all the railroads entering the city of Boston from the south, was first seriously considered. During the first six months of that year a suitable site was selected and a large part of the land acquired.

The engineering force, with Mr. George B. Francis at its head, reported for duty on July 1st, and active surveys immediately commenced. While this work was in progress, the manager of the terminal, Mr. John C. Sanborn, and the chief engineers of the interested roads, visited various European railroad terminals; the architects and engineers were preparing plans and a fund of information bearing on the project was accumulated. Among other data thus collected was that shown in the accompanying map (Fig. 155). This diagram shows the need for large terminal facilities in Boston, and the exhibit made justifies the existence of the new South Station, the largest railroad station in the world.

In anticipation of revolutionary changes in the methods of handling suburban traffic, it was decided to so build the new station that new motive power could be advantageously employed, and so that a large increase in suburban trains, due to smaller train units and more frequent service, could be easily handled.

In the first plans made, all tracks were arranged on a single floor; but after providing as well as possible for all train service and for desirable features for handling baggage, and after developing several methods of handling electric cars, it was ascertained that no more than 28 tracks could be secured, while the aggregate of tracks in the stations which the South Station replaces, was 25.

There being no reasonable hope that a greater width of land could be secured, consideration was given to the possibilities of

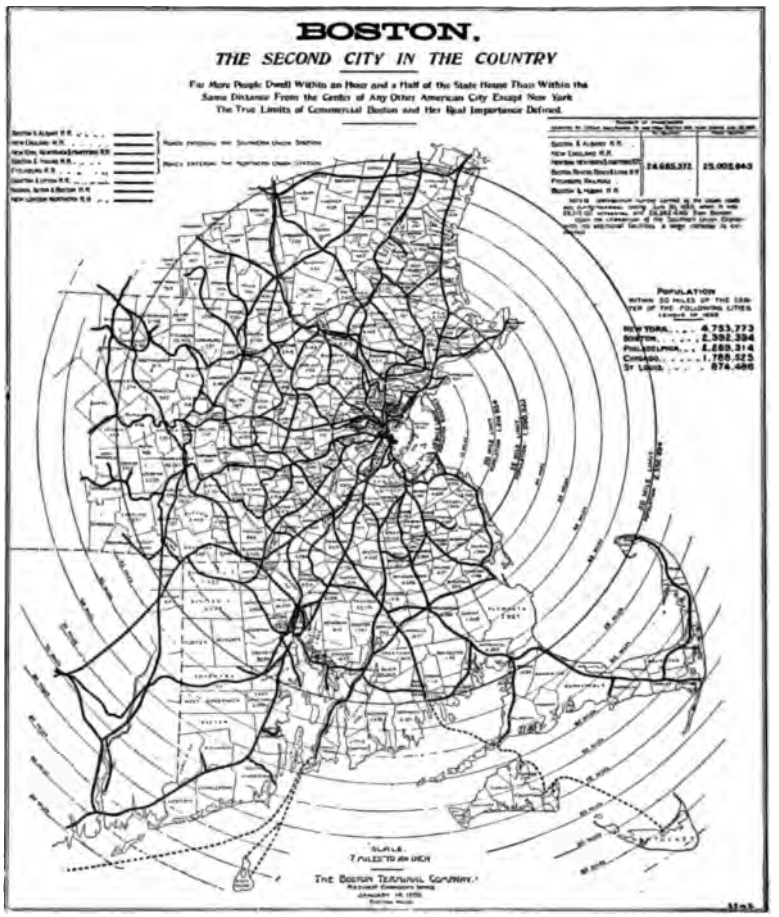


FIG. 155.—MAP OF THE TERRITORY WITHIN FIFTY MILES OF BOSTON.

Showing railroad routes northerly and southerly of an east and west line; the former routes leading to the north terminal station, and the latter to the south terminal station.

About 50,000,000 passengers are carried to and from Boston by these routes each year, nearly equally divided between the two stations.

The close approximate population within the 50-mile or, say, suburban limit is 2,392,000. Within the same limit around Philadelphia it is 2,259,000; around Chicago, 1,788,000; around St. Louis, 874,000; and around New York, 4,754,000; New York only exceeding Boston.

separating the suburban short distance service from the through or long distance service, placing them at different levels, thereby greatly increasing the room for the tracks in a given area.

The first study of the problem diverted the proposed suburban tracks from the main approach tracks about half a mile from the station, and by a gradual rise brought several tracks on either side of the train shed to a level about 24 feet above the main floor. These were to be stub-tracks like those on the floor below. This arrangement did not do away with the necessary switch system for making up trains outside the station for each floor level, and upon its development it was seen that if the elevated stub-tracks could be connected in the form of loops, the train movements would be very much lessened and the number of switches at the entrance largely reduced. The great width of the station made this possible and it was accordingly done.

This was, therefore, the first loop study. There was much doubt regarding the advisability of having upper platforms about 28 feet above the main floor, as would be the case if high platforms were used, on account of appearance, stair climbing, handling of baggage, and the smoke and steam from the locomotives below. The approaching grades were also steeper than was desirable.

The possibility of a suburban loop track service upon a floor beneath the main train shed was next considered. The main floor was raised to the highest level practicable without the use of stairs and the level of the loop tracks determined at a grade 17 feet lower and some 8 feet below very high tides. This immediately introduced the study of waterproofing the great loop area to shut out the tide water, and due consideration indicated that this could be done without prohibitive cost.

Placing the loop tracks 17 feet below the main floor level and using high platforms for the loop service, made easier approach grades; stairways of 13 feet rise instead of 28 feet, as in the case of the elevated loop; simplified the handling of the baggage; improved the appearance of the main floor; and overcame all trouble from smoke and steam from locomotives.

The one very important thing that was thus accomplished was the making of the great terminal a through station for one kind of service, and a terminal station for the other. Suburban trains do not carry mail, express matter, or baggage in any quantity. They carry people only, and should be run frequently and be got

out of the way quickly. The through-station loop feature makes it possible to handle as many trains at the terminal as can be run over the main line. Moreover, as the new terminal must eventually provide for suburban trains from four main lines—the Boston and Providence, Old Colony, New England, and Boston and Albany railroads—such trains must leave the station at shorter intervals than trains could be run on either main line alone. This is accomplished by providing two loop tracks, arranged with a minimum number of switches, to be used alternately, each track being capable of holding several trains.

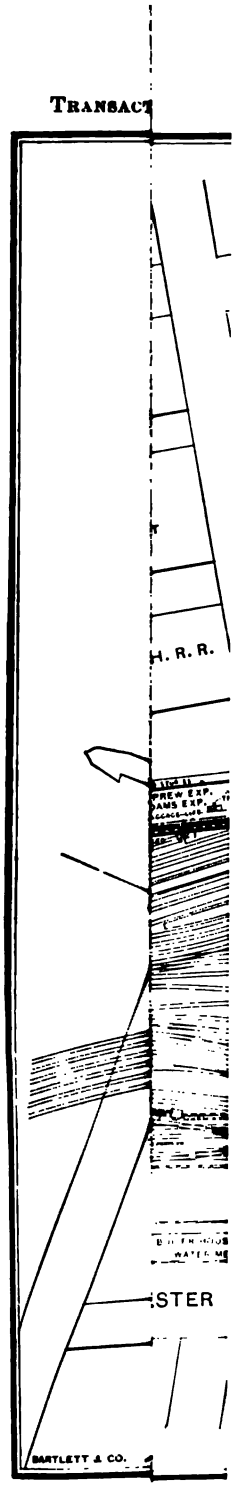
The separation of platform levels, thus accomplished, still made special provisions necessary for the expeditious and safe handling of baggage. Nine baggage and express trucking platforms running the entire length of the train shed, independent of the passenger platforms, were provided, and an underground passage was designed to allow the baggage trucks to cross beneath the tracks.

The civil engineering was well developed along these lines under the direction of Mr. Francis, and a head house designed by the architects, Messrs. Shepley, Rutan & Coolidge, of Boston, when an opportunity was afforded Westinghouse, Church, Kerr & Co., acting on behalf of the various Westinghouse interests, to consider the engineering requirements of the terminal other than embraced in the track and structural work, and to prepare plans and specifications for a complete mechanical installation.

The accompanying reproduction of a general plan of the property (Fig. 156) shows the prominent features of the terminal so far as determined at that time. This drawing shows the arrangement of tracks and buildings in the yard necessary for the safe and expeditious handling of trains. In all, about 750 trains have been transferred to the new station, involving daily something over 4,000 movements through the switches in 18 hours.

The specific problem presented involved the detail design of a complete equipment most suitable to the needs and uses of this large railway terminal. Such an equipment was considered to be a means to an end rather than an end in itself; and in all things due regard was had to the fact that a railroad terminal, rather than a mechanical equipment, was to be built and operated. As a result, many things were done that would not have been, had the conditions and requirements of the terminal, from a railroad standpoint, been different.

In connection with the work, careful investigations were made


TRANSACT
H. R. R.
STER
BARTLETT & CO.

of the features and needs of other important railroad terminals in this country and abroad, a vast amount of data and information of a valuable nature was accumulated and used so far as available; but by reason of the great size of the new station, and particularly the unique character of some of its prominent features, many problems were presented of a kind not heretofore met in such work.

The solution of the problem which was finally presented embraced the following principal items:

1. The complete installation of an electro-pneumatic system of switching and signalling.
2. A power-house equipment.
3. An electric wiring installation for arc and incandescent lighting, and for electric power for various uses.
4. Passenger and freight elevators, baggage and express lifts.
5. Apparatus for warming and ventilating the head house, and heating yard and express buildings.
6. Ice-making plant to supply ice for cars, restaurants, etc.
7. Refrigeration for restaurant, kitchen and storage boxes, and flower booth.
8. Filtering and water cooling plant to furnish supply of drinking water.
9. Car heating in train shed, storage, and express yards.
10. Compressed air supply for charging and testing train brakes.
11. Fire protection for the various buildings and train shed roof.
12. Disposal of storm water and drainage from waterproofed structure.
13. Frost protection for roof conductors.
14. Steam and hot water supply for head house.

The substantial gains in simplicity, first cost, and in operating expense possible with the opportunity to design this complete engineering equipment in which many kinds of service are involved, each of which was considered merely a branch of one comprehensive system, are known to have been very large. They followed in a larger measure, because of the opportunities provided at an early period to harmonize conditions and details of other construction with the requirements of the entire system, and to remove obstacles to the employment of the most suitable apparatus and methods.

FIG. 158.—JUNCTION OF MAIN SUBWAY FROM POWER HOUSE WITH DORCHESTER AVENUE BAGGAGE WING BASEMENT. THE PROMINENT PIPE IS THE 8-INCH HOT WATER FLOW MAIN FOR HEATING PLANT.

Thus, while the intrinsic merits of any piece of apparatus were always given due weight, it was possible, where other things were equal or nearly so, to allow considerations of adaptability to the general system to determine a choice, and in this way to simplify the whole to a great degree. Simplicity in general design, and few kinds of service, not only led to an averaging of the various demands on the source of power, thereby improving conditions and reducing the capacity necessary to provide, but manifestly led to a reduced cost of attention and skill required for operation and maintenance.

In general, it may be said that the several items of work which have been mentioned are all provided from a centralized system derived from a central power plant generating but one pressure of steam, and involve only the following classes of service:

1. Electric current on a uniform system wherever used.
2. Water distribution under simple conditions.
3. Air and ammonia compression.

The good results following this kind of treatment are very marked as compared with those obtained where little or no regard has been paid to general considerations of suitability, and specific instances are not wanting to forcibly illustrate the difference.

In the general design the problem of distribution was an important one. The territory to be served was large, the buildings long and narrow, and virtually cut in two by the presence of waterproofing at the main suburban exit, by the loop tracks, and by prohibitions placed upon carrying pipes over the main waiting room. The existence of this restricting "throat," as it was called, tended to complicate the already difficult problem of conveying light, heat, refrigeration, fresh air, power, and other service in the large quantities required at points far distant from the only available site for power house without excessive costs, and without employing conduits of almost impracticable dimensions. The further desire not to allow such obstructions to detrimentally affect the selection of apparatus and methods best adapted to the perfecting of a complete system, together with other considerations of an important nature, led to the use of some unusual features of design. Many of these would not have been possible at a later period in the undertaking, when facilities could not be easily created and obstacles readily overcome.

In general, loop circuits were employed wherever this could advantageously be done. The "main" and "transverse" subways

shown on drawing, were provided especially for this purpose, and made this possible. Other circuits were advantageously divided, with branches distributing through the main and transverse subways. In this way sizes and costs were greatly reduced, the required means much simplified, and the narrow throat (indicated by subway *S.D.*) made adequate, although only a comparatively few inches in its greatest allowable transverse dimensions.

The greatest latitude was also secured in the selection of apparatus, and important economies both of first cost and of operating expense made possible. The use of a heating system employing rapidly circulating hot water as a distributing medium effected large savings in cost, and enabled the varying quantities of exhaust steam—a waste product of another portion of the general system—to be stored and utilized to a greater degree than possible by any other method, besides avoiding the complications incident to the handling of drips in the waterproofed portions of the property below sewers, high water, and boilers. Thus, also, the use of electricity for operating the 24 elevators and baggage lifts avoided the introduction of a system of hydraulic machinery which, under the conditions prevailing at the terminal, would have been costly and somewhat complicated.

The opportunity to use a loop-feeder circuit for the elevator machines enabled power to be supplied in a manner calculated to allow the current flow to "average," and to secure the largest benefits from the inter-operation of the several machines.

These and other features of the installation will be mentioned more at length in the descriptions which follow. Allusion is made to them here for the purpose of pointing out and emphasizing the fact that, although much care and time were necessarily devoted to perfecting all details of the plant, that the best thought and endeavor were put on the fundamental design of the entire system considered as an operative whole. The engineering importance of this cannot be overestimated. It is only in connection with such treatment that skill in detail design can produce the best possible results.

Power House.

The general arrangement of the power house (Fig. 160) was determined by important considerations of track facilities and traffic requirements, leading to what some one has aptly termed a

FIG. 159.—POWER PLANT BUILDING. ICE PLANT LOCATED IN LEFT-HAND END. STACK SHOWS AT RIGHT OF VIEW. ONE OF THE SIGNAL BRIDGES IN FOREGROUND.

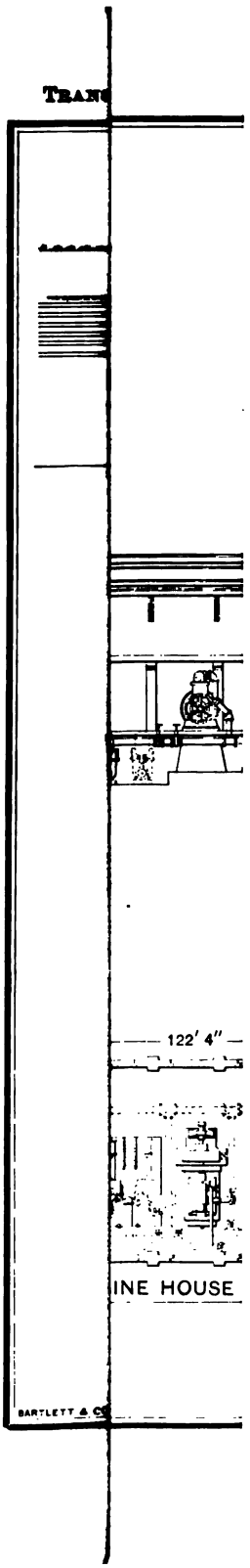
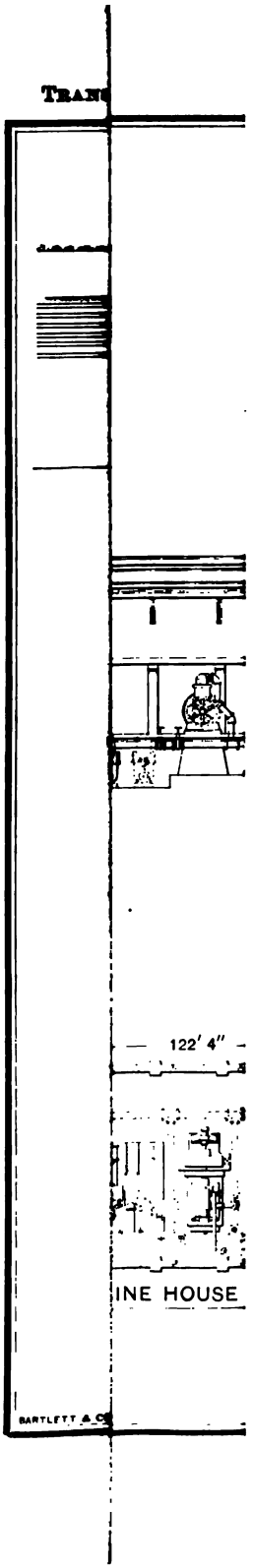

TRANS
122′ 4″
INE HOUSE
BARTLETT & CO

FIG. 159.—POWER PLANT BUILDING. ICE PLANT LOCATED IN LEFT-HAND END. STACK SHOWS AT RIGHT OF VIEW. ONE OF THE SIGNAL BRIDGES IN FOREGROUND.


TRANS
122' 4"
INE HOUSE
BARTLETT & CO

"tandem layout." It was evolved from a series of designs superior from an engineering standpoint, but less well adapted to fulfil all conditions or meet certain restrictions which were imposed. This form of plant was therefore determined upon only after full consideration of the many factors bearing on the work.

In designing this plant the fact was kept strongly in mind that the expense, including interest on investment, of operating the daily service of so large a terminal would be very heavy, with no opportunity for earning. It was therefore imperative that it should operate with a high commercial efficiency, and that it should be of a simple type and design, with minimum cost of attendance. The conditions did not permit economy to be sought through the use of abnormal pressures, complicated machinery, or extreme refinements.

The principal apparatus is contained in a well-lighted and well-ventilated brick building erected especially for the purpose, occupying a space 460 feet long and 40 feet wide on the easterly side of the yard. The plant furnishes power, light, heat, and refrigeration wherever required throughout the premises, and is the source of all the mechanical service that the terminal requires. So far as possible, precautions have been taken against accidental interruption of the service, and substantial relay has been provided throughout, either by the use of complete "spares," or through a choice of units which permits the loss of the use of one without impairment of service.

The boilers are set in one battery, and are of the horizontal return tubular type 72 inches in diameter, measured on the outside of the small course. There are 10 in all, and each contains 130 three-inch tubes 18 feet long. The shell plates are $\frac{1}{2}$ inch thick, rolled from a special quality of acid open hearth fire box steel. The heads are of acid open hearth flange steel $\frac{9}{16}$ inch thick. All material entering into the boilers was made to special specifications, and was required to meet rigid tests before acceptance. The longitudinal seams have quadruple riveted butt joints arranged to come above the fire line, and boilers are designed for a working pressure of 145 pounds per square inch. The use of this type of boiler was determined by considerations in which there was full acquiescence, but which would not necessarily have a bearing on other similar work.

The boilers are suspended from 8-inch I beams securely fastened together, and arranged in pairs so that suspender bolts

FIG. 161.—VIEW OF BOILER ROOM, SHOWING ROney MECHANICAL STOKERS.

pass between the beams. The settings are lined with fire-brick throughout, and tops of boilers are covered with 2 inches of asbestos fire felt and asbestos cement.

The boiler plant is provided with an equipment of Roney Mechanical Stokers and Smokeless Furnaces (Fig. 161) adapted to burn widely different qualities of fuels, including anthracite or bituminous coals, "front ends" from locomotives, or various mixtures with the highest economy, without change of grates and without smoke. These stokers are the labor savers in the boiler room, and effect also a material saving in fuel.

The use of coal and ash-handling machinery was fully considered. This problem was complicated by the fact that much heavy construction beyond the power house was in such an incomplete state that no immediate provision could be made for handling water coal or to arrange for the future handling of rail and water coal indiscriminately. Several plans were devised which met all conditions satisfactorily; but for reasons which have no engineering interest, the installation of coal-handling machinery was deferred. Changes afterwards found necessary in the boiler-house structure seriously interfere with the full benefits to be derived from the present use of such apparatus. An inexpensive and satisfactory expedient for handling coal from cars to stoker hoppers was, however, devised and reasonable emergency storage provided. This arrangement consists of an overhead track capable of holding a loaded coal train, and arranged for dumping coal through scuttles to a false deck on a level with stoker hoppers, or through traps to the floor of the boiler house according as it may be desired for immediate use or storage.

The waste gases from the furnaces are conveyed through a suitable flue of heavy steel plate with angle-iron stiffeners, and covered with 2 inches of asbestos fire felt and cement, to a pair of improved circulating economizers of the form developed by the engineers. These economizers are provided with necessary dampers and by-pass, the arrangement being such that economizers may be used singly, in parallel, or in series with each other as the conditions of service may allow, thereby permitting the greatest possible savings to be made at all times.

The products of combustion are cooled by the economizers to a point at which natural draught could not be employed, except by the use of a chimney so high that its cost and the cost of its foundation would be prohibitive.

FIG. 162.—VIEW LOOKING TOWARD MECHANICAL DRAFT PLANT FROM TOP OF BOILERS. ECONOMIZERS AND FEED PIPING IN FOREGROUND.

Draft is furnished by a pair of large, slow-running fans, either of which is of sufficient capacity for an ultimate installation of five more boilers in addition to the ten now installed. Provision is made in the boiler room and in the design of the machinery for this additional equipment. The fans have "three-quarter" housings and vertical discharge, and are proportioned and designed in detail to meet the special service demanded of them in furnishing draught for steam boilers. Their wheels are of special construction and proportions, and are carried on heavy forged steel shafts running in water-jacketed boxes, the wheel shafts being connected to engine shafts by marine couplings. The engines are horizontal. One engine and its fan always lie idle as spare, dampers being provided so that either fan may be operated at will. Regulation is controlled by variation in steam pressure, the arrangement being such that a uniform pressure of steam is maintained in boilers by control of draft through regulation of fan speed.

The waste gases are discharged from the fans through a self-supporting iron stack 11 feet in diameter, and extending but a few feet above the power-house roof.

The feed pumps are in duplicate, and their steam ends are compounded. The water ends have outside packed plungers. The discharge is carried to economizers, auxiliary feed-water heater, and boilers in such a way that the heater, either or both economizers, or any boilers may be by-passed or used at will.

All hot feed water piping is of brass, the largest being 4½ inches diameter. The boiler blow-offs are 3 inches in diameter and are carried to a suitably vented blow-off tank with the ordinary connection to sewer. Each blow-off is provided with a gate guard valve and an angle blow-off valve, both extra heavy.

Steam is conveyed from the boiler house to the engine room and ice plant through a line of 12-inch piping arranged in form of a loop, the arrangement being such as to avoid the complexity usually accompanying a duplicate system of piping; at the same time permitting the isolation and repair of any part without impairment of service. All flanges on the principal live-steam mains are steel and are welded to the pipe. All fittings are cast iron, extra heavy. Long bends of iron pipe are used wherever turns are made, except in two cases where it was necessary to use copper. No expansion joints are used anywhere in the plant, it

FIG. 163.—PIPING OVER BOILERS. EACH BOILER HAS TWO CONNECTIONS WITH SUPPLY MAINS, ONE TO EACH SIDE OF THE LOOP. ALL FLANGES ON THIS PIPING ARE WELDED STEEL AND ALL JOINTS ARE COVERED. NO EXPANSION JOINTS ANYWHERE IN THE PLANT. ECONOMIZER AND MECHANICAL DRAFT PLANT IN BACKGROUND.

FIG. 164.—MAIN LIVE-STEAM PIPING IN ENGINE-ROOM BASEMENT—FLANGES, WELDED STEEL; JOINTS COVERED.

FIG. 165.—VIEW IN ENGINE ROOM DURING CONSTRUCTION.

having been possible to design this system of piping in a manner to make their use unnecessary. The miscellaneous service requiring live steam and auxiliary apparatus is supplied by a system of auxiliary piping having its origin in both sides of the main loop, but otherwise independent of it. Particular attention was paid to the design of the live-steam piping in power house with reference to handling water of condensation, and steam loops have been provided for returning such water automatically to the boilers.

Steam is carried directly from the steam main through large radius bends to each of the main engines. The initial installation consists of four engines of the Westinghouse compound single-acting type. The nature of the service at the terminal is such that loads on these main engines vary greatly from hour to hour, day to day, and season to season. At times use can be made of even more exhaust steam than the engines yield; at other times there is a surplus which is condensed in vacuum. The conditions were therefore not favorable to the use of receiver types of compound engines, although an indefinite tendency to prefer Corliss engines, and a willingness on the part of the engineers to use them, led to a full consideration of their capacity for saving under the conditions which existed.

To this end all the engine loads throughout the twenty-four hours of a day were carefully charted for every month of the year, and curves were plotted to represent corresponding quantities of exhaust steam required for heating. The number of pounds of water exhausted per hour by the engines of each type, when carrying the charted load, was used to plot curves of exhaust steam available for heating purposes. The Corliss type of engine was credited, without regard to the effect of variable loads, with the lowest water rate claimed by its makers at point of greatest steady load economy. The only times when steam would be wasted and an opportunity to save would exist would be when the exhaust exceeded the heating requirements, due allowance being made for the value of the heat-storage capacity of the body of water in the heating system. The three accompanying plates are typical of the twelve charts that were prepared, and illustrate the method of determination employed, each load being carefully considered and separately plotted. The possible saving was the difference in the amount of steam exhausted to atmosphere (or condenser) by the two types of engines, in excess of the amount

FIG 166.—STEAM AND EXHAUST PIPING IN ENGINE-ROOM BASEMENT.

FIG 166.—STEAM AND EXHAUST PIPING IN ENGINE-ROOM BASEMENT.

required for heating. This was determined for each month in the year, and the amount of saving so calculated showed the amount in dollars to be insignificant as compared with the considerable additional expense involved.

Due consideration was necessarily given to the choice of units for the most economical and reliable performance of this work, and four 18″ and 30″ by 16″ engines, aggregating 1,500 nominal indicated horse-power were used, each being direct-connected to a 225-kilowatt engine type generator. The engine shafts are extended to take the generator armatures, and are provided with outboard bearings, the complete generating units being mounted on heavy cast-iron bedplates. Each engine can be run either condensing or non-condensing; the exhaust piping being so arranged that this can be done at will while engines are running.

The vacuum side of system is connected with a Deane independent steam condenser located in pit in engine-room basement. The atmospheric side of system connects with central heating plant of the heating and ventilating system, and free exhaust is provided through an 18-inch relief valve. This main exhaust system also receives the exhaust steam from all other sources in the plant.

A hand travelling crane, having a lifting capacity of 40,000 pounds, spans the plant, and is arranged to traverse the entire length of engine room and compressor room of ice plant.

Interlocking Switch and Signal System.

To thousands daily entering and leaving this largest of American railway terminals, its magnitude is represented by the great area of its train-shed floor; by the number and extent of the tracks laid thereon; by the proportions of the shed and head house, and by the incessant flow of humanity through its portals.

Comparatively few give more than a passing thought to the intricate track approach, and but few realize how utterly dependent is the punctuality of the station's traffic upon the arrangement of the tracks and the manner of their manipulation.

"All tracks look alike" to the average individual, and the ends, rather than the means of reaching them, generally interest him most. However far from public attention, and subordinate to other features this one may appear to be, it nevertheless is of the first importance to the station's management, and involves more

FIG. 170.—ENGINE ROOM IN POWER HOUSE.

dependency upon the part of its employees, than does any other of its departments. The magnitude of the station's plan; the manner of its execution; the capacity of its train shed and head house, together with the comforts and conveniences afforded the travelling public, are matters of interest only so long as punctuality marks the arrival and departure of trains. Punctuality of traffic would not have resulted if proper regard for the traffic's schedule had not been a potent factor in the design of the switch system handling it.

At the present time (October, 1899), 737 trains enter and leave the new station daily, 65 of these within an hour in several instances. Within the two minutes between 5:15 and 5:17 P.M., 6 trains depart and 3 arrive. The average train consumes one and one half minutes in passing from or to the station through this switch system. Evidently the nine trains mentioned must be passing through it at the same instant. Accommodation for nine simultaneous train movements is therefore essential to punctual service, and is necessarily a feature of the track arrangement for handling the schedule. Upon this track system *eleven* simultaneous movements may be made to or from the train-shed floor, while four additional movements may, at the same time, be made on the depressed tracks of the suburban loop system beneath it, making possible a total of fifteen simultaneous train movements.

Capacity for simultaneous train movements alone is, however, not the only requirement of a well designed track system; it is also important that means be provided for the direct movement of traffic from one track to another, and for the simultaneous execution of many such movements. It is further desirable that these facilities shall not involve special frogs and other appliances difficult of repair and renewal; that switches shall be so placed that they may be signalled comprehensively and in the simplest possible manner, and that they will occupy the minimum amount of space for the facilities they afford the traffic. The accompanying plan (Fig. 171) of these tracks shows how these requirements have been met in the design of the yard tracks.

When this plan is examined in connection with the statement made concerning train movements, the necessity for rapid and accurate manipulation of its switches is apparent.

Without some means of accomplishing this, and without a comprehensive system of signals working in conjunction with it, such

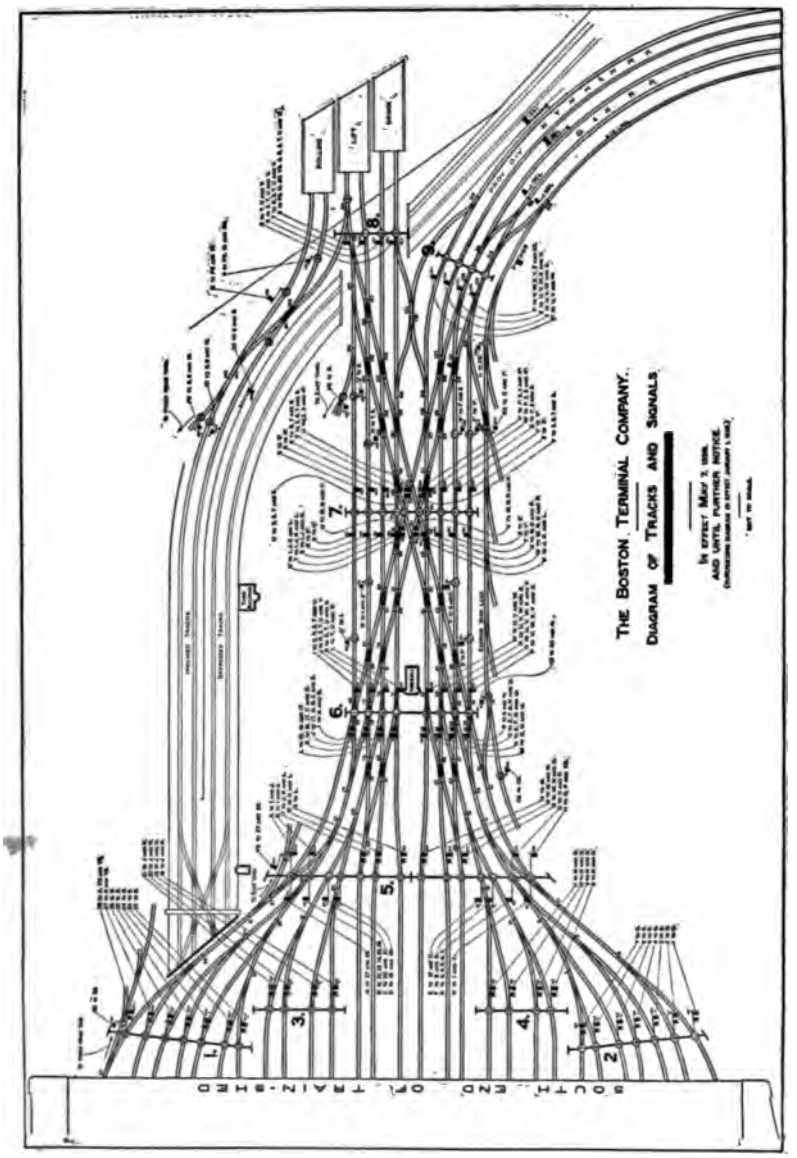


FIG. 171.—DIAGRAM OF TRACKS AND SIGNALS OPERATED FROM TOWER NO. 1, GIVING FUNCTIONS OF SIGNALS AND THEIR DESIGNATING NUMBERS. (REFER ALSO TO FIG. 153.)

a traffic would be in constant peril of derailment or of collision; hence the custom of placing fixed signals at suitable points throughout a switch system, and operating them from a central point by means of levers arranged in convenient proximity to like levers similarly connected to, and operating, the switches.

Two systems of interlocking were fully considered with regard to their application to the requirements at this terminal: the mechanical, and the electro-pneumatic. In both, the machine levers are so controlled one by another that signals cannot be given for trains to proceed until all switches in the route governed are first properly set and locked, and conversely so that the switches of a route governed by a signal cannot be moved during the display of a signal giving right of way over them.

Several plans were carefully prepared for both systems. The mechanical apparatus for the principal tower (No. 1) for working the switches and signals of the surface tracks in accordance with the best practice, would involve the use in it of about 360 levers, which, at the customary spacing (5-inch centres), would necessitate a tower at least 160 feet long. The lead-out for such a machine would occupy, if arranged in the usual manner, practically all of the space now devoted to the use of storage tracks, capable of holding 67 cars. Evidently such a sacrifice could not be made, and by way of demonstrating a means of avoiding it, the lead-out was arranged vertically along the wall of the subway, in one of the plans submitted. It involved the use of rocker shafts of such a length, that their construction, to avoid undue loss from torsion in them, would have been cumbersome and otherwise unsatisfactory.

A second plan for avoiding the sacrifice of the storage yard embraced an arrangement of the lead-out over the subway upon a deck supported by beams extending from one retaining wall to the other. This arrangement was also unsatisfactory; first, because it necessitated many jaws, cranks, and other connections which materially increased the already excessive loads put upon the levers (due to the heavy rails of the switches, and to the friction incidental to long connections between them and their operating levers); second, the objection to encumbering the subway with overhead structures outside of the station proper.

The plan involving the electro-pneumatic interlocking avoided these serious objections, and possessed desirable features which were of such vital importance that its adoption at this place

became almost a matter of necessity. The principal reasons that governed the decision may be summed up as follows:

In the mechanical system the levers employed are massive iron affairs connected to the switches by lines of 1-inch pipe suitably guided and deflected by roller bearings, bell cranks, etc., so that the motion imparted to the lever by its operator is transmitted directly to the switch.

Signals are similarly operated; wire frequently being used, however, as a substitute for the heavier pipe connections. The energy required to operate a switch by this means naturally varies greatly with varying conditions. The size of the rail from which the switch is made; the stroke of the switch; the length of the pipe line operating it; the alignment and lubrication of this line, and, finally, weather conditions, all influence the ease with which the levers of such an apparatus are shifted, and hence the ease with which the labor of the operator is accomplished.

The inability of an operator to shift by this means the load frequently permitted by traffic conditions to be attached to one lever oftentimes compels the use of several levers where one would be ample were his energies unlimited. Notwithstanding this subdivision of the work of one lever between several, the labor of shifting the levers of a mechanical apparatus is fatiguing in the extreme where much traffic is handled, and where this labor is, consequently, continuous for hours at a time.

A mechanical tower would be so large and its lead-out so extensive, that it would have to be at the side of the yard and so far from the central field of operation as to render a clear view from it of all the tracks impossible under many anticipated conditions. Not a small consideration, too, was that of the difficulties to be encountered in constructing permanently the leads of a mechanical plant on filled ground and under the adverse conditions presented for such work, during the progress of other construction work, interfering with these to a greater or lesser extent.

The pneumatic interlocking system, on the other hand, necessitated the use of only about one-third the number of levers required by the mechanical system, and a very much smaller force of men for its operation. By reason of the smaller number and closer concentration in its machine frame of the levers involved it required a tower of but one-fourth the length of that necessary for the mechanical system. It therefore permitted the location of tower No. 1 upon ground not required for other purposes, and

in a position giving the best view of the switches and signals operated.

Having no movable connections between the tower and the switches and signals, it involved no likelihood of interference with its operation from future settlement of the filled ground.

The number of levers employed in the pneumatic system is subject only to the restrictions imposed by traffic requirements upon the number of switches or signals that may be operated simultaneously from one lever. It does not involve that physical restriction, peculiar to the mechanical system, resulting from the natural limitations of an operator's energy and of the period through which he is capable of exerting it. In this connection it is interesting to note that instances are frequent in the Boston South Station interlocking plant where a single pneumatic lever operates a number of slip switches and movable frogs, their locking mechanisms and detector bars, that would require in a mechanical system four, and, in some cases, five levers for their operation.

The method of mounting the pneumatic signal lever permitted the operation from it of more signals than is practicable from a mechanical one. These levers have a central position normally, and are movable to the right and to the left of this position for working separately, but under the control of the locking, two or more signals governing conflicting routes.*

The first cost of a mechanical interlocking proved to be considerably greater than that of the electro-pneumatic, and the cost of operation and maintenance was found to be greatly in favor of the electro-pneumatic.

The amount of traffic handled by an interlocking does not bear any fixed ratio to the size of its interlocking machine, and one operator is occasionally able to handle an apparatus of 40 levers, that under other traffic conditions would prove burdensome to two.

While no general rule exists as to the number of men required for the operation of machines of various sizes, and though no rule will probably ever apply to this work in practice, an assumption was made that when the full limit of any interlocking is approached in the operation of trains through it, the assignment of more than 20 levers to a man is overtaxing his ability to stand for 8 consecutive hours the work to be performed. Hence the 360

* Five or six signals are frequently operated by one lever in the Boston Terminal's interlocking.

levers that would be necessitated for the terminal interlocking, if of the mechanical type, would entail the employment of 18 levermen for their operation. The pneumatic system required but three. The hours of labor for each day being divided into three shifts of 8 hours each, two of these shifts required 3 levermen each, and the night shift 2, making a total of 8 levermen daily.

The mechanical plant, allowing 18 levermen for each of two shifts and but 6 for the night shifts, would employ 42 levermen daily. The average rate of pay at important places for levermen is about $75 per month. The 42 mechanical men would receive yearly $37,800; the 8 pneumatic men yearly $7,200; leaving a yearly balance in the latter's favor of $30,600.

The use of electricity as a controlling agent and of compressed air for actuating the mechanism of the electro-pneumatic system, entirely eliminated the question of distances in the problem of the operation of the switches and signals. Their use enabled the automatic control of signals by trains to be accomplished in a simple and reliable manner, and value was also attached to their flexibility. These and other important reasons led to the adoption of the Westinghouse electro-pneumatic system after mature consideration on the part of those having the matter in hand of all possible systems for the new terminal.

This system as installed, consists of the following elements: an engine for compressing air to the desired pressure and in the required volume; a receiving tank; a condenser and a pipe line extending to the extremities of the interlocked system of switches; a cylinder attached to, and adapted to operate, each switch and signal; an electro-magnetic valve mounted upon, and controlling the pressure from, the air main to each cylinder; electric wires extending from these magnets to the levers of the interlocking apparatus in the tower; an interlocking machine so constructed that the manipulation of its levers causes electric currents to be applied to or removed from the wires connecting with the valve magnets, and an electric generator for supplying the necessary current.

The air supply is derived from one or the other of two 14-inch by 18-inch Ingersoll-Sargent Piston-inlet Compressors (Fig. 172), alternation from one to the other being made every twelve hours.

Each compressor is capable of compressing 352 cubic feet of free air per minute at its maximum speed of 120 revolutions. Service at the Boston South Station rarely calls for a speed exceeding 30

revolutions, however, and the actual consumption of air by the interlocking during its busiest minutes probably does not exceed the equivalent of 100 cubic feet of free air.

Large reserve capacity is an important consideration at this and similar places, where a breakdown that exhausts the air from the pipe line and reservoirs would be attended with serious delays to trains if not rapidly repaired and the pressure quickly restored. For this reason, large compressors are employed.

In order that the moisture held in suspension by the superheated air, immediately after compression, may be precipitated at a point convenient of drainage and before it is passed into the service main, where in extreme cold it would prove troublesome, the air is conveyed from the receiving tank at the compressor through a system of manifold pipes of large surface area exposed to weather influence, and is thus brought to the temperature of the atmosphere again by radiation, the effect being to precipitate much of the moisture into a reservoir suitably arranged to receive it and provided with a blow-off for expelling it periodically.

At each switch and signal cylinder is placed a small auxiliary reservoir connected with the service main and the switch or signal valve in such a manner that the air, drawn from the main during operation of these devices, passes through the reservoir and deposits therein whatever sediment or remaining moisture it may contain after having passed through the condenser.

The air pressure employed in the system is about 80 pounds per square inch, thus permitting of small piston and pipe areas, compactness of operating mechanisms, and economical transmission of the air through long distances.

There are three interlocking towers in the terminal installation—one for the approaches, one for the suburban loop tracks, and a third for the terminal yard. The main tower (No. 1) is the one of chief interest, and is situated on the centre line of the terminal, midway in its switch system. The interlocking apparatus is located in the building, and comprises 130 levers for operating 91 high home signals, 36 cautionary signals, 21 dwarf signals, 31 double slips with movable frogs, and 49 single turnouts; which represent a total of 148 signals, and the equivalent of 233 single switches.

The switches and signals of the suburban tracks are located at their entrance to the head house, under the train-shed floor, and being simple and few in number, possess no special feature of

FIG. 172.—PAIR OF INGERSOLL-SARGENT AIR COMPRESSORS, LOCATED IN MAIN ENGINE ROOM, FOR SUPPLYING COMPRESSED AIR TO THE ELECTRO-PNEUMATIC INTERLOCKING SWITCH AND SIGNAL SYSTEM. ICE PLANT AT REAR OF VIEW.

interest not also common to the larger system on the surface, except that they are operated from an independent tower known as No. 2, and by a distinctly separate apparatus from those of the surface system. This tower is located on the west subway retaining wall, immediately opposite the switches handled from it, and the interlocking apparatus therein contains 10 working levers and 1 spare lever, the former operating 4 double slip switches with movable frogs, 4 single turnouts, and 8 dwarf signals.

The machines for all the towers are alike in principle, and are provided with two types of levers—one for the operation of switches, and one for the operation of signals; the handles of the former standing somewhat above those of the latter. Each lever is adapted to rotate a shaft extending from it to the rear of the machine through an arc of 60 degrees, and by these shafts the several functions of the apparatus are performed.

The forward ends of these shafts lie under and at right angles to a series of bars extending from end to end of the machine. In each of these bars a rack is cut which engages a segmental pinion keyed to one of the shafts, so that the partial rotation of the shaft by its lever produces a longitudinal motion of the bar engaging it. Metal "dogs," which give motion to smaller and shorter bars suitably guided at right angles to and above them, are mounted upon these bars. These engage or disengage the dogs of other bars, and thus prevent or permit their operation, and consequently govern the movements of their operating levers.

It is this mechanism that constitutes the "interlocking" of the apparatus, and renders such vital service to the operator in preventing serious results accompanying errors or oversights on his part during his manipulation of its levers.

Back of this "locking bed" lies a hard rubber plate over which the shafts also extend. The shafts here are covered with hard rubber tubing carrying metal bands that extend partially around them, and which are arranged (when the lever is moved) to form or to sever metallic connections between metal strips that are mounted upon the rubber plate immediately under them—these strips constituting parts of the various electric circuits controlling the valves of the switches and signals operated. The circuit of each valve may be thus controlled by any one or all of the levers in the machine as circumstances may require.

To the rear of this rubber plate and supported by the machine frame, immediately under and engaging the extremities of the

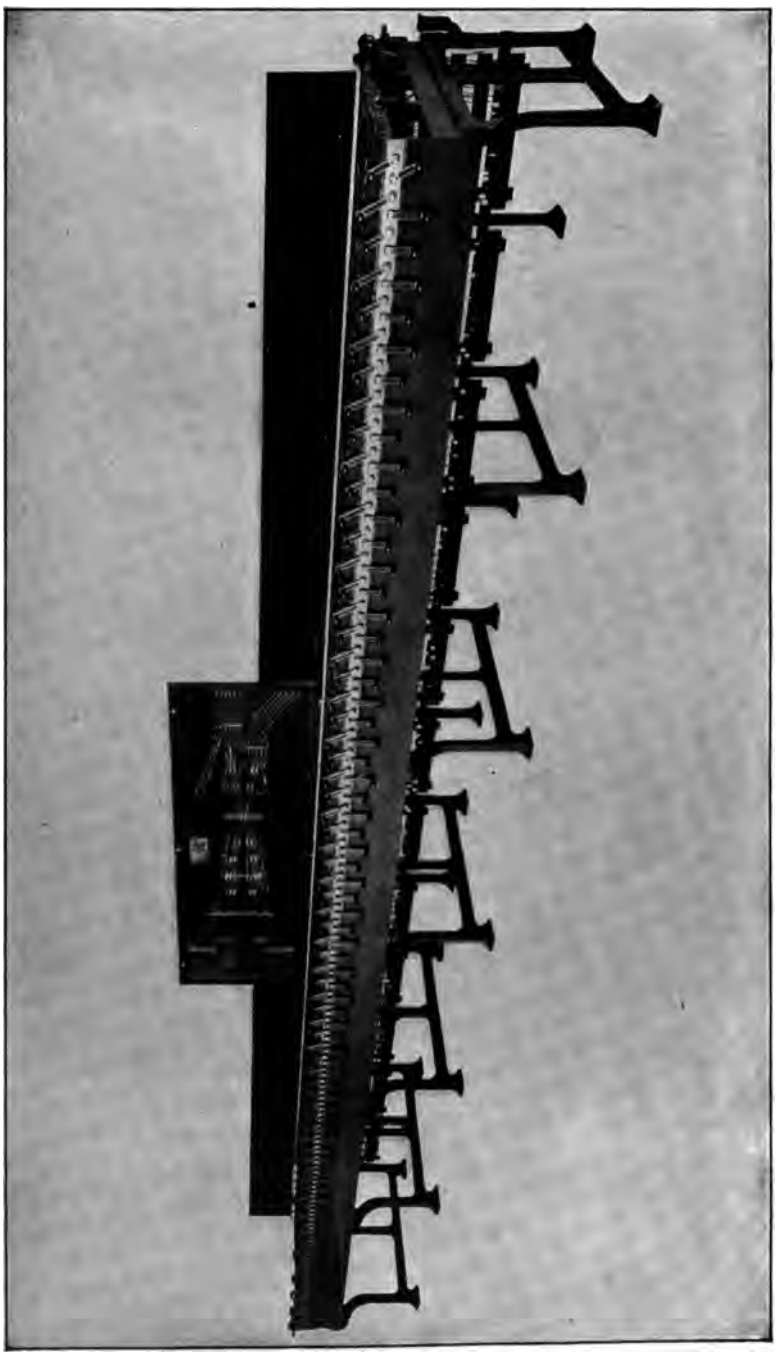


FIG. 173.—FRONT VIEW OF INTERLOCKING MACHINE IN TOWER NO. 1. OPERATING MORE SIGNALS AND SWITCHES FROM A SINGLE POINT THAN IS DONE BY ANY OTHER APPARATUS IN THE WORLD.

shafts, are two rows of electro-magnets. These magnets are controlled by motion and position of the switch or signal operated from the lever engaged by each, and are designed to insure that the lever and switch or signal shall coincide in position before the lever can be given its full movement—which movement is essential to the display of any signal giving right of way through the interlocking.

Electric current for the system is provided by a duplicate set of chloride accumulators of 300 ampere-hours capacity, that is charged from a rotary transformer driven by current from the main power house, and which delivers to the batteries 20 amperes or less, at an electromotive force of 25 volts, as required. The maximum output of the batteries for all purposes is about 5 amperes for the interlocking at the new South Station—the 6 cells maintaining a minimum potential of 12 volts at the interlocking machine.

The medium by which the switches and signals are moved by their respective levers in this system has not the power, of itself alone, to detect failure of the former to respond to the latter, and obstructions in switch points or incomplete movements of switches or signals from other causes might, if not detected with certainty, result in serious derailments or collisions; hence the necessity for these precautionary provisions.

A characteristic feature of the pneumatic interlocking machine is the "track model." Mounted vertically over the machine frame is a black metal board upon which a miniature model of all tracks operated is formed of light brass strips. The switches of this model move in harmony with those on the ground, and at all times correctly represent the actual track connections within the interlocked territory.

The number of signals required for an interlocking system is determined largely by the extent of territory covered by its tracks and by the frequency and nature of the train movements made over them. Considering safety alone, the minimum number of signals essential to the protection of any switching plant is represented usually by the number of tracks upon which trains may enter it. When the territory covered is small, or when the traffic is light or composed wholly of "through" movements, as at grade crossings and junctions, the minimum number is usually ample. Where movements are not all "through;" where the track system is of large area, and where many movements are involved, neces-

FIG. 174.—REAR VIEW OF ELECTRO-PNEUMATIC INTERLOCKING MACHINE IN TOWER NO. 1 (CABINET REMOVED).

sitating frequent and rapid shifting of trains and engines, as at this large terminal station, many additional signals are necessary to insure expeditious service; hence the large number employed.

Of these signals, 128 are mounted upon 9 iron truss bridges spanning the tracks governed by them. All are mounted on iron posts, and conform to the New York, New Haven and Hartford standard with respect to form, position, and color, which, by virtue of a recent decision, involves the use at night of a red light for danger, a yellow one for caution, and a green one for safety. Below each of 28 signals, which govern trains starting from the station, there is a distant signal, which, when cleared, indicates that all advance home signals of the routes governed by them are also at "clear." There are also 8 cautionary signals to govern trains in-bound to the station.

Trains automatically control the latter by rail circuits formed of the tracks from the bumping posts within the shed to their points of intersection without the shed, and they move to safety with the home signals above them only when the shed tracks are unoccupied. The failure of one to thus move with the signal above it is an indication to an approaching engineer that the track he is about to enter is already partially occupied, and that he must enter it cautiously.

Each signal is so constructed that it rests by gravity in the danger position; hence a *single*-acting cylinder only is required to shift it. This cylinder is of 3 inches diameter and 4 inches stroke, producing an energy, with 80 pounds of air, equal to the elevation of about 187 pounds one foot, thus permitting the use of a counterweight sufficiently heavy to insure certainty of the signal's return to danger under the most unfavorable weather conditions.

In the "dwarf" signal, where heavy counterweights are inconsistent with compactness of design (an essential feature of this type), a stout coil spring is substituted for gravity to a great degree.

The small volume of air used to move these signals is controlled by a valve under the control of an electro-magnet. These valves are of the "pin" variety, and are readily shifted by the energy of the magnet above them. When the magnet is de-energized, the combined influences of the pressure and a coil spring under the admission valve hold the latter seated and the exhaust valve above it open, thus permitting the free exit of pressure from the cylinder in ordinary operation, and also preventing its ac-

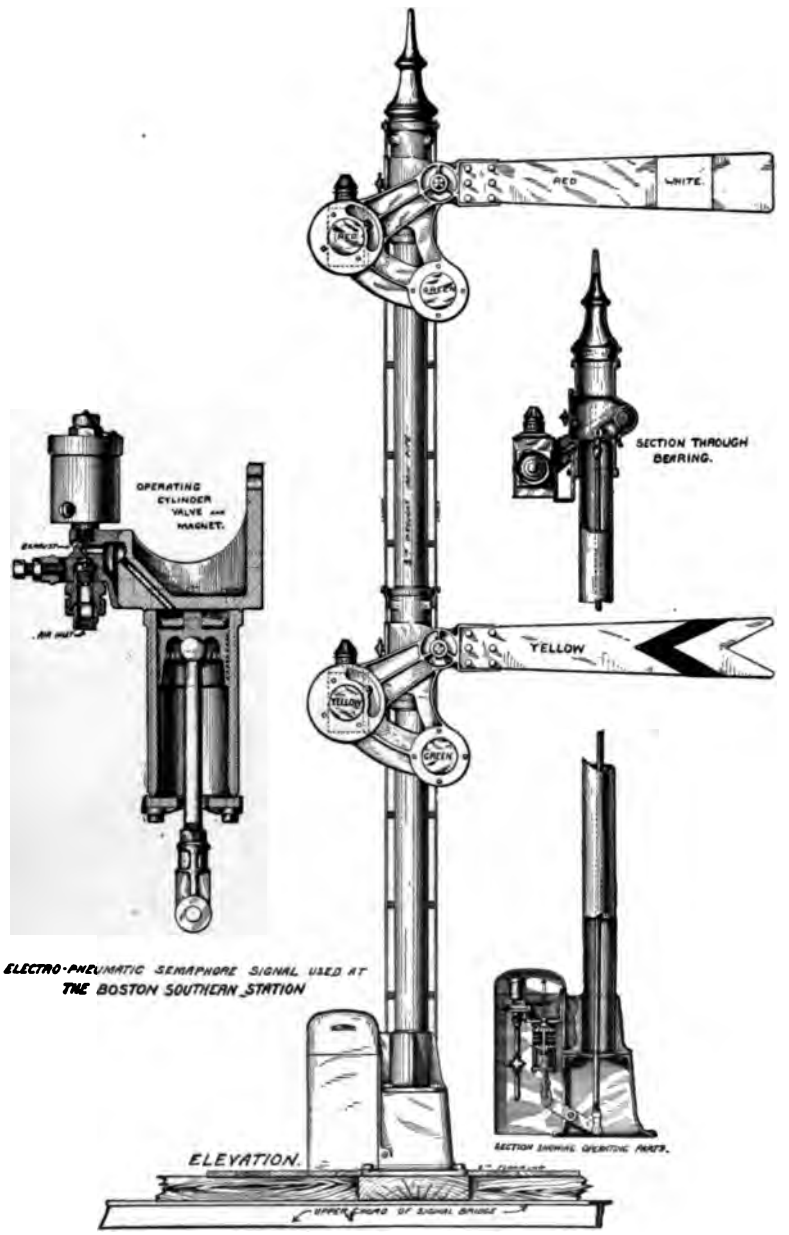


FIG. 175.—TWO-ARMED ELECTRO-PNEUMATIC SEMAPHORE SIGNAL, SHOWING OPERATING MECHANISM AND INTERNAL CONNECTIONS (FOR USE ON SIGNAL BRIDGES).

cumulation therein should a leak develop in the admission valve. When the magnet is energized, the exhaust is closed and the pressure is admitted to the cylinder, whereupon the piston, overcoming the signal's counterweight, moves the signal to the safety position.

On each signal movement, so arranged as to be opened the instant the signal moves from the danger position, is a pair of contact springs controlling a circuit extending to, and including, an electro-magnet actuating a lock engaging the signal lever.

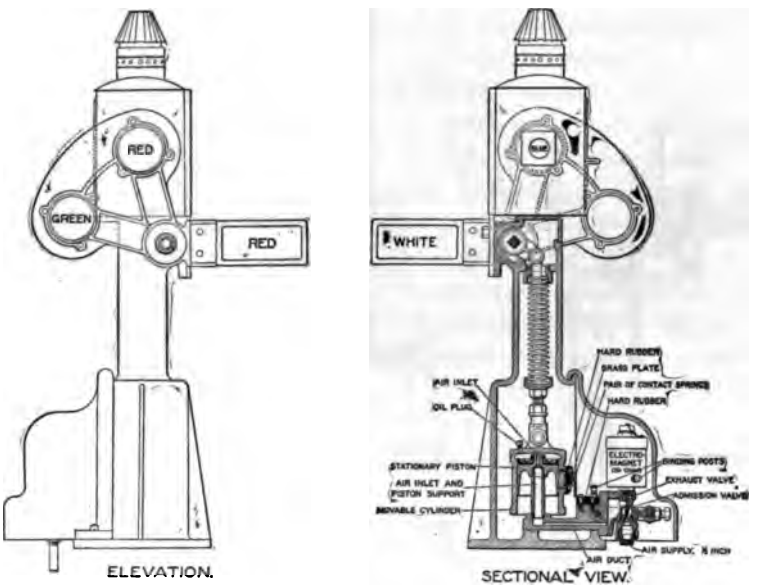


FIG. 176.—ELECTRO-PNEUMATIC DWARF SIGNAL FOR "DRILL" OR "SHUNT" MOVEMENTS, SHOWING OPERATING MECHANISM.

Each lever, upon moving a signal to safety, thus becomes electrically locked by the signal itself, and cannot be completely returned to normal until the signal has returned to danger. This is effected by a *partial* movement of the lever toward normal, the lock being so applied as to permit of this with the signal at safety. Any failure of a signal to return to danger thus prevents the return of its operating lever to normal, and until this is effected the switches governed by the signal cannot be moved.

Signals are designed to return to danger by gravity, not for simplicity's sake, nor for any convenience the method may entail in their operation; but are so designed to secure the greatest degree

of safety to traffic during an abnormal condition of them or their operating connections. Gravity, being a force that can be invariably relied upon, is used to hold the signal at danger when any one or all other forces employed for its operation are rendered inactive.

The failure of a signal to move to safety when safety exists may produce delay, but nothing more serious; to fail to move to

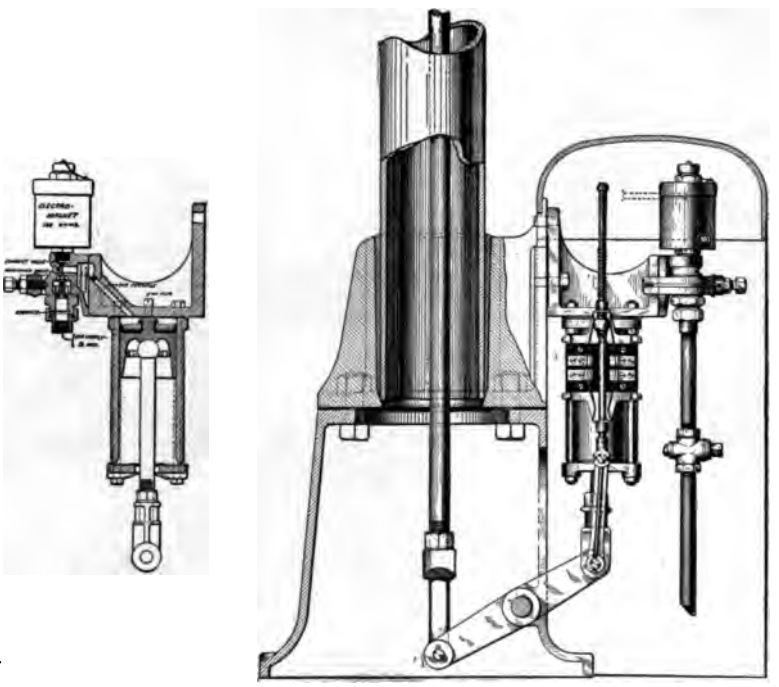


FIG. 177.—ENLARGED VIEW OF OPERATING MECHANISM FOR ELECTRO-PNEUMATIC SEMAPHORE SIGNAL.

danger when danger exists is a vastly more serious matter. The same reasons, or equally good ones, do not apply to the retention of switches in one position by gravity, nor is the attempt made to so operate them, for this and for obvious other reasons; hence the cylinders operating them are *double* acting, and they are consequently equipped with two magnetic valves, one at each end.

The comparatively large volume of air used by a switch cylinder (6-inch diameter, 8-inch stroke) is, however, not so readily or so quickly handled by the pin valves (before mentioned as operated

by electro-magnets and as controlling directly the pressure to signal cylinders), and those employed for switch operation, therefore, are arranged to control the pressure to the switch cylinders *indirectly*. They control the motion of two small auxiliary cylinders secured to the side of the switch cylinder, which have mounted between their piston ends a slide valve of the usual steam-engine type, which readily admits and discharges the greater volume of air used by these cylinders.

A bolt locked to the slide valve is made a feature of the design. The lock consists of a plunger applied normally by a stout spring to a recess in the slide valve, and which is withdrawn by exhausting the air from above the plunger by means of a third magnetic pin valve, thus permitting the full pressure in the valve chamber to overcome the spring and force out the bolt. When the magnet is de-energized, the exhaust-pin valve is closed, and the pressure, by passing through a small hole drilled through the plunger's piston, gradually balances the latter and permits the action of the spring to again lock the slide valve.

In operation this lock must be withdrawn before an attempt to shift the slide valve will be successful, and the electric contacts of the switch lever are so arranged that the three magnetic valves of the switch mechanism are operated in proper sequence to withdraw the plunger previous to each attempt to shift the valve.

Whatever the provision for preventing unintentional operations of switch levers by levermen, the best of these are liable at some time or another to make the attempt and to succeed in spite of the precautions taken. To guard as far as possible against disaster accompanying such cases, switches are equipped with what are technically termed "detector bars." These are of a length equal to the wheel base of the longest car, and lie just below rail level against the outer sides of the stock rails of switches. They are mounted upon radial links pivoted in brackets secured to the rail flanges in such a manner that a longitudinal movement of the bars is also accompanied by an upward movement of them above rail level. The fore part of the bar's motion precedes the unlocking of the switch and any motion to the latter. A train standing or passing over a switch prevents motion being given the bar, and hence protects itself against derailment resulting from attempts to move the switch under it.

The Old Colony Railroad (now Plymouth Division, N. Y., N. H. & H.), whose former terminal was at Kneeland Street, near the

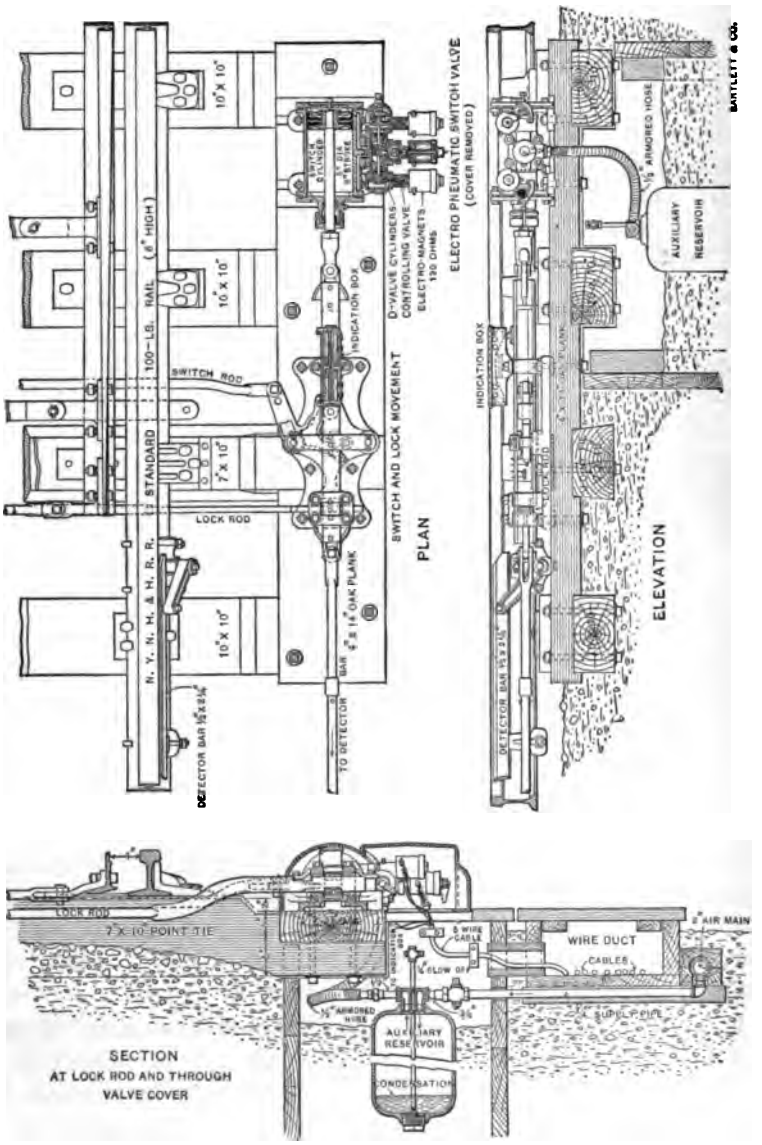
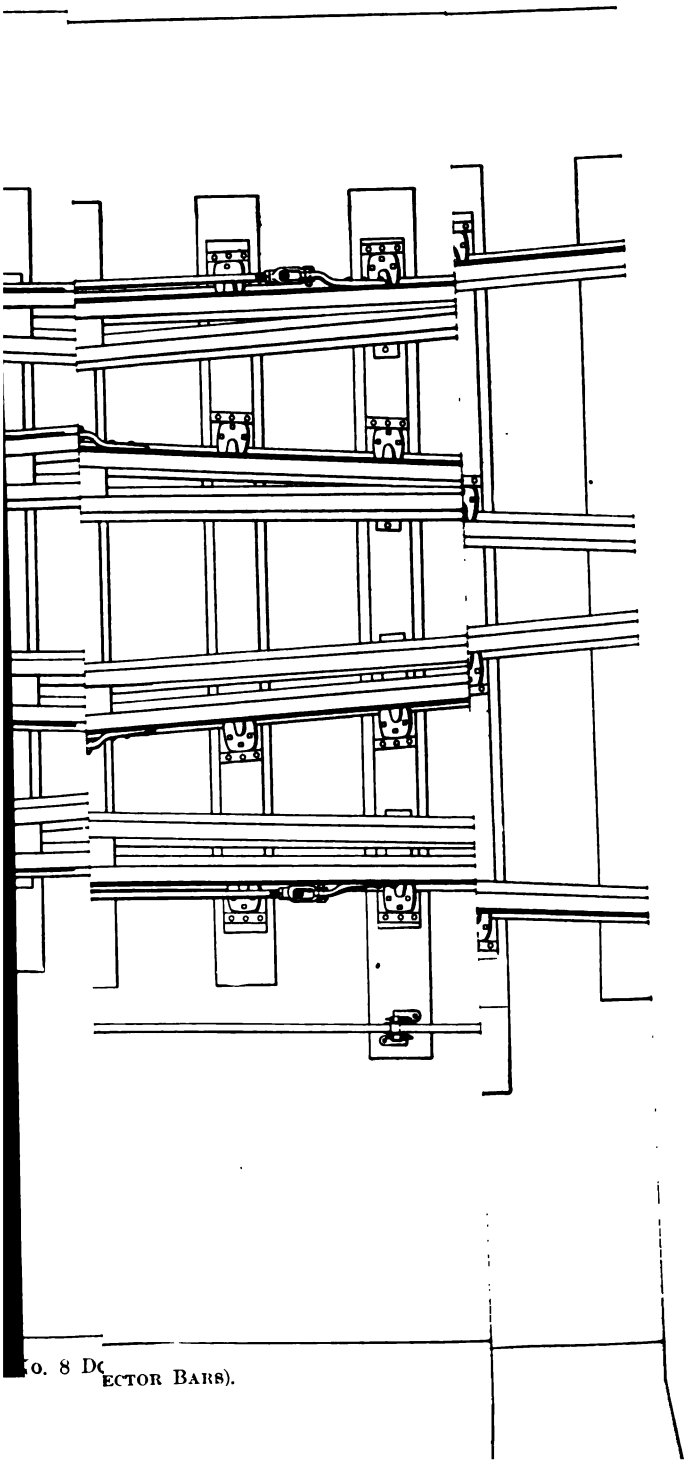


FIG. 178.—ELECTRO-PNEUMATIC OPERATING MECHANISM APPLIED TO A SIMPLE SWITCH.



o. 8 D ECTOR BARS).

south end of the new yard, and the New England Railroad (now Midland Division, N. Y., N. H. & H.), which formerly had its station on the site of the present head house, began using the new station on January 1, 1899, and to accommodate the 250 trains of these divisions a portion of the terminal's tracks was put in use on that day with switches and signals worked from a temporary pneumatic machine located in a temporary cabin near tower No. 1, the yard not being then sufficiently completed to admit of the erection of all the signals and connections of the final arrangement.

On May 7th, the permanent tower and machine were put into service, and a large part of the permanent interlocking was then ready to receive the 192 trains of the Boston & Albany Railroad, which entered the new station on July 23d, thus making a total of 444 trains using the station on that date.

On September 10th, the Providence Division of the N. Y., N. H. & H. R. R. transferred its traffic from the Park Square Station to the new station, and these trains swelled the total up to the present figures, 737 trains.

It was decided, shortly after the opening of the station to traffic, to divide its shed tracks into sections, assigning certain tracks to the B. & A. R. R. and others to each division of the N. Y., N. H. & H. R. R., rather than to attempt to operate one side of the station exclusively for inward and the other for outward trains, as was originally contemplated. This became almost a necessity for another reason: During the morning the shed is filled rapidly with incoming trains and in the evening by outgoing trains, which frequently occupy 80 per cent. of the station's tracks, and thus would encroach beyond a division line, were one drawn.

While the surface tracks of the new station permit of handling upon them more trains in a given time than is possible by the track arrangement of any other *terminal station* in this country, the added facilities presented by the suburban "loop" system beneath it gives it a capacity largely exceeding that of any other station in the world. The actual capacity of the loop system is as yet unproven, as its use is held in abeyance pending the solution of certain motive power problems affecting the traffic for which it is intended.

The capacity of the surface tracks is demonstrated, however, and though these tracks are as yet not all completed, and though much that is completed lies idle, pending the completion of two of

the three leaves of the drawbridge over Fort Point Channel, the heaviest summer traffic of the Consolidated and the Boston and Albany Railroad systems was handled with no inconvenience or delay upon that portion in use.

In addition to the usual telephone and telegraphic equipment and such annunciators as are used for announcing trains approaching the station, a set of 28 annunciators (one for each station track) is arranged in the bay of the tower, for the announcement by conductors of the readiness of trains to leave the station. At three points along each track within the shed special push buttons are provided for actuating these annunciators. Each conductor notifies the despatcher in the tower, and receives an acknowledgment, which is sent by act of restoring the annunciator drops. Above these annunciators is arranged a set of 28 indicators (one for each shed track), which are automatically actuated by trains within the shed by means of the rail circuits formed of the shed tracks, so that constant evidence is thus had of the presence or absence of cars upon any of these tracks.

Although the method of operating the station did not contemplate train movements being made except in the normal direction, provision is nevertheless made in the interlocking apparatus for such movements. Signals cannot be given for these movements, however, without the coöperation and consent of the director, who, when the lever combinations have been made for them, may clear the signals permitting them, by means of a magnetic key under his control. The leverman has the power to restore to danger the signals thus operated, but cannot, under any circumstances, move them to safety unassisted by the director. Such train movements should, in general, be prohibited; but owing to the large number of "shunts" or "drill" movements at this place, provision was made for them in the interlocking.

This provision naturally requires another in the signal system, which is to prevent the approach of trains towards the terminal, on the inward tracks, during outward movements upon them. These provisions being made, the maximum capacity of the station's tracks may be utilized in the event of emergencies without undue risk of collision between trains.

The plant is under the direct care of a supervisor of interlocking, who has charge of its operation and maintenance. The operating force consists of a directing despatcher and assistant, a telephone attendant, a telegraph operator, and three levermen.

The maintenance force consists of a general repairman and two assistants during the day and a repairman and helper during the night.

The yardmaster has direct charge of traffic, and has one or more assistants, as circumstances require. The maintenance of tracks is under a roadmaster of the terminal company.

The directing despatchers issue to the levermen orders for such manipulation of the interlocking apparatus as are necessary for the train movements to be made. The telephone attendant controls a switchboard connected with the various departments of the station proper and with the departments of the several roads using the station, while the telegraph operator has charge of all telegraphic communications, train reports, records of delays, failures, etc. The levermen manipulate the interlocking apparatus to permit the movement of traffic called for by the director. The directors and operators are located at the station end of the tower in a bay-window constructed so as to give opportunities for views of the tracks in all directions.

The interlocking machine occupies a floor area of 6 feet by 30 feet, and the tower a ground area of 14 feet by 42 feet. The hours of duty consist of three shifts of 8 hours each, and each man was the subject of careful investigation as to his fitness before his appointment to duty.

The Electric Plant.

The application of electricity to the service of the terminal comprised the following:

For incandescent lighting.....	650	horse-power	connected	load.
" arc lighting.....	200	"	"	"
" general motor service.....	320	"	"	"
" elevators and baggage lifts....	381	"	"	"

This service was to be distributed over an area of approximately 1,100,000 square feet of floor space besides the yards, the maximum distance from the power house being about 3,000 feet. In addition to the foregoing, a very small amount of current was required for use in connection with the system of switches and signals, for operating clocks, etc. There were reasons why the alternating system could not be used; therefore, the problem to be solved involved a selection from among continuous-current types, the question of voltage, the number and size of units, and a suitable method of con-

trolling and distributing the current. A conception of the amount of electrical service to be rendered is had by noting that in arc lighting alone there are but three cities in Massachusetts outside of Boston and the municipalities contiguous thereto in which there are a greater number of municipal arc lights than those used by the terminal.

Considerations of floor space alone were almost sufficient to make necessary a universal system; *i. e.*, one in which all classes of service are supplied by the same generators, even if economy of first cost and of maintenance had not, as they did, also weighed in the same side of the scale.

A careful comparison of the conditions prevailing in other terminals made it possible to determine with close approximation the hourly demands of each class of electric service, and to construct therefrom superimposed load diagrams, showing the probable output of the generating plant for every hour of the day. On this information, due regard being had for other conditions, the unit selected was a 225-kilowatt Westinghouse generator, three being sufficient to handle present maximum loads and a fourth remaining as a relay.

Provision is also made for the addition of further units should increased service be required in the future. It was desired to secure the advantages of economy and of service afforded by the use of 110-volt incandescent lamps; also the low first cost for conductors and the good regulation permitted by the three-wire system, as well as the 220-volt motor service possible thereby. The small size and great number of the generating units required by this system as ordinarily installed, however, would have not only seriously increased the floor space as well as first cost of apparatus, and further very materially reduced the efficiency and increased the cost of maintenance, but would have necessitated anything but an ideal station arrangement. An ingenious method was therefore devised for constructing three-wire generators, each capable of supplying both 110 and 220-volt current at the same time. This method is used here in just this way for the first time.

In the ordinary three-wire system, two 110 to 125-volt generators are connected in series, and the three wires of the system are attached, the two outside ones to the extreme terminals of the machines, and the middle wire between them. One hundred and ten volt lamps are then connected between the middle and each of the outside wires, but the middle wire only carries current

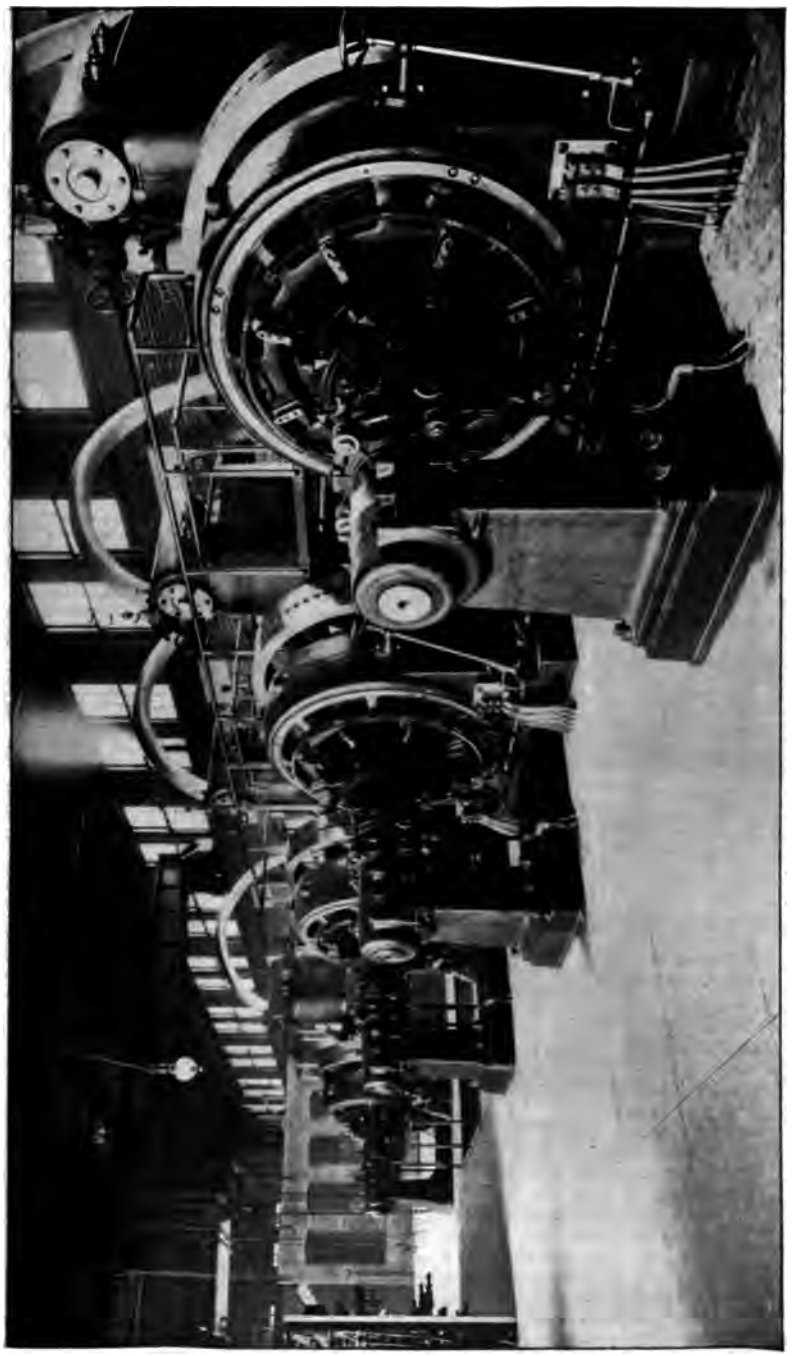


FIG. 180.—INTERIOR OF ENGINE ROOM IN POWER HOUSE, SHOWING GENERATORS.

representing the difference between the load connected to the two sides of the system. When these two sides are evenly balanced, as it is always the aim to have them, no current at all flows on the middle wire, and the pressure of the system is 220 instead of 110 volts. This means that conductors of one-fourth the size will serve to distribute the energy with a given loss. The advantages of such a saving are sufficiently obvious, but the disadvantage, which is especially prominent in small installations, lies in the necessity of always running two machines, no matter how small the load may be. This means smaller sized units, lower efficiencies, greater first cost, larger floor space, etc. The Boston Terminal Company's machines practically reproduce the three-wire conditions, but condense each two small machines into one machine of twice the size. Of course, two machines might be built into one, by mounting two armatures on the same shaft and putting two sets of fields on the same frame. This, however, would be a change in name only, as the efficiency, number of parts to maintain, floor space, first cost, etc., would not be materially changed. Likewise, an attempt to put two windings on the same armature introduces difficulties, as, in the modern generator, every available inch of space is already utilized for winding. The plan adopted for the terminal machines was to make generators with standard windings to give 220 to 250 volts, and to connect the middle wire of the system to the middle or neutral points of these windings. This arrangement reproduces in effect practically all the features of the usual three-wire system, without, however, any of the disadvantages above mentioned. The method of accomplishing this middle connection is the novel feature of this machine installation, and is as follows:

Two leads are brought out from the rear of the armature winding 180 degrees apart, and are connected through collector rings to the terminals of a suitable stationary choking or balance coil surrounding an iron core. As the current from these leads has not passed through a commutator, it remains an alternating current, and the counter electromotive force set up in the choking coil balances the electromotive force of the generator, and prevents the flow of current. However, if the middle point of the coil be connected to the neutral wire of the three-wire system, the presence of an alternating current in the coil does not interfere with the otherwise free flow of the continuous current through the neutral wire, and the passsage into the armature

FIG. 181.—NO. 4 ENGINE AND GENERATOR. MAIN SWITCHBOARD AT LEFT OF VIEW. ICE PLANT AND TWENTY-TON TRAVELLING CRANE IN BACKGROUND. CONDENSER PIT SHOWS IN FOREGROUND.

through first one half of the coil, and then the other half, as the alternating current reverses its direction of flow. Where the difference between the loads of the two sides of the system is small the capacity of the balance coil may be correspondingly small, and as such is the case at the South Station, it is found that one moderate-sized pair of balance coils is sufficient for the entire system when all four generators are in service. This method provides, therefore, an opportunity for the best conditions of service outside the power plant, combined with the most economical and efficient arrangement within.

The four 225-kilowatt dynamos in the generating plant are of the multi-polar (10 poles) compound-wound type with fields vertically divided, and are mounted each on the extended shaft of a Westinghouse compound engine, the general arrangement being elsewhere described more in detail.

Generator cables are carried under the floor to the switchboard.

The main switchboard is complete and comprehensive, combining great flexibility and ease of control with simplicity. It consists of polished white marble panels placed side by side and containing the desired switching, indicating, and controlling appliances; those for the generators occupying one end, and those for the feeders the other, with load panel between, thus permitting the addition of either more generators or extra feeders in the future without disturbing the original board. All generators are arranged to run normally in multiple with each other; but in order to provide against the possible disturbance of the system by any one or more circuits, and to permit the greatest possible flexibility in operation, a second set of bus bars is provided, on which any machine or circuit or combination of machines and circuits may be thrown at will. An ammeter, a circuit breaker, and a field rheostat are connected to each generator.

The problem of the distribution and control of current was not a simple one. In its final solution it involved 18 feeder circuits connected to the main switchboard, and in general leading to corresponding distributing centres. These feeders are as follows:

Feeder	No.	1. Public lights in head house.
"	"	2. Basement lights in head house.
"	"	3. Lights in restaurant, barber shop, etc.
"	"	4. Inward baggage rooms, platform, and outside.
"	"	5. Outward baggage rooms, platform, and outside.

Feeder	No.	6. Midway, train shed, front of building, and entrance.
"	"	7. Suburban platform.
"	"	8. General offices.
"	"	9. Suburban tunnel.
"	"	10. Express office and platforms.
"	"	11. Power house.
"	"	12. Interlocking towers and sump lighting.
"	"	13. Elevator motors.
"	"	14. Basement fans.
"	"	15. Attic fans.
"	"	16. Sump motors.
"	"	17. Signal lights.
"	"	18. Roll lift drawbridge motors.

At the terminus of each principal lighting feeder is a subsidiary switchboard mounted in a cabinet and kept under lock and key. The various distributing circuits are controlled from these secondary boards, and, so far as desirable, made independent of the power house attendants, although adequate provisions are made to compel full coöperation in the manipulation of the current.

This is accomplished by means of an annunciator system with push buttons at each distributing centre, and annunciator on load panel of main switchboard. Pilot lamps, installed on the distributing boards, show whether the boards are "dead" or "alive;" the normal condition being "dead." The push button is pressed when current is desired, and the pilot lamps show when the feeder switch on main board has been closed. This arrangement secures the very best of service, enables the operating force at the power house to take advantage of opportunities to shut down generating units when not needed, and makes it impossible to throw large loads on the power house without adequate notice. Pressure wires are run from each distributing centre to corresponding voltmeters on the main switchboard in power house.

The system of wiring is necessarily very extensive and varied. A large part of the feeder work and basement wiring is open construction with weatherproof wire and porcelain insulation. All concealed work is conduit construction, using high class rubber insulated wire with double protective braid and unlined iron conduits.

Advantage was taken of the opportunity to run loop feeders in some instances, notably in the case of No. 8 feeder, which supplies current for office lighting distributed throughout a building having

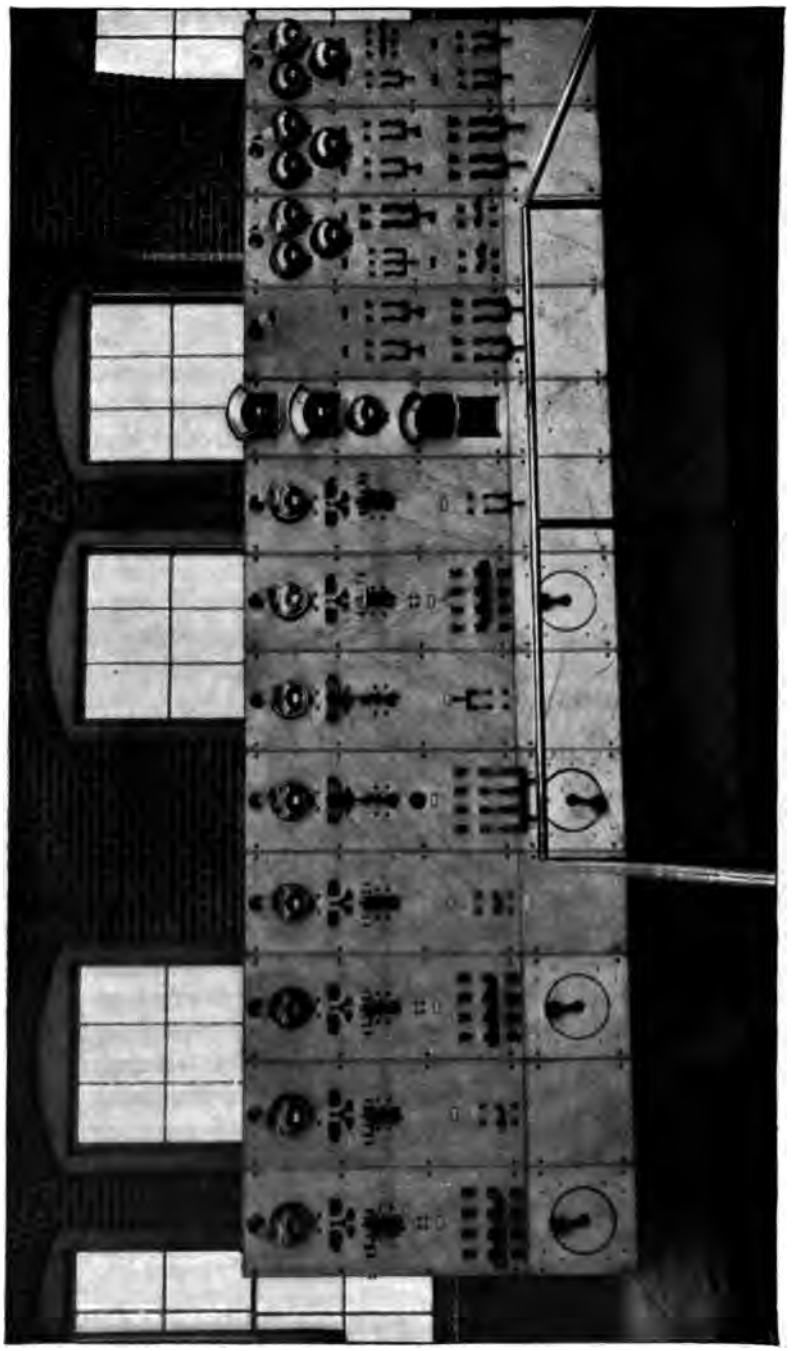


FIG. 182.—MAIN SWITCHBOARD IN POWER HOUSE.

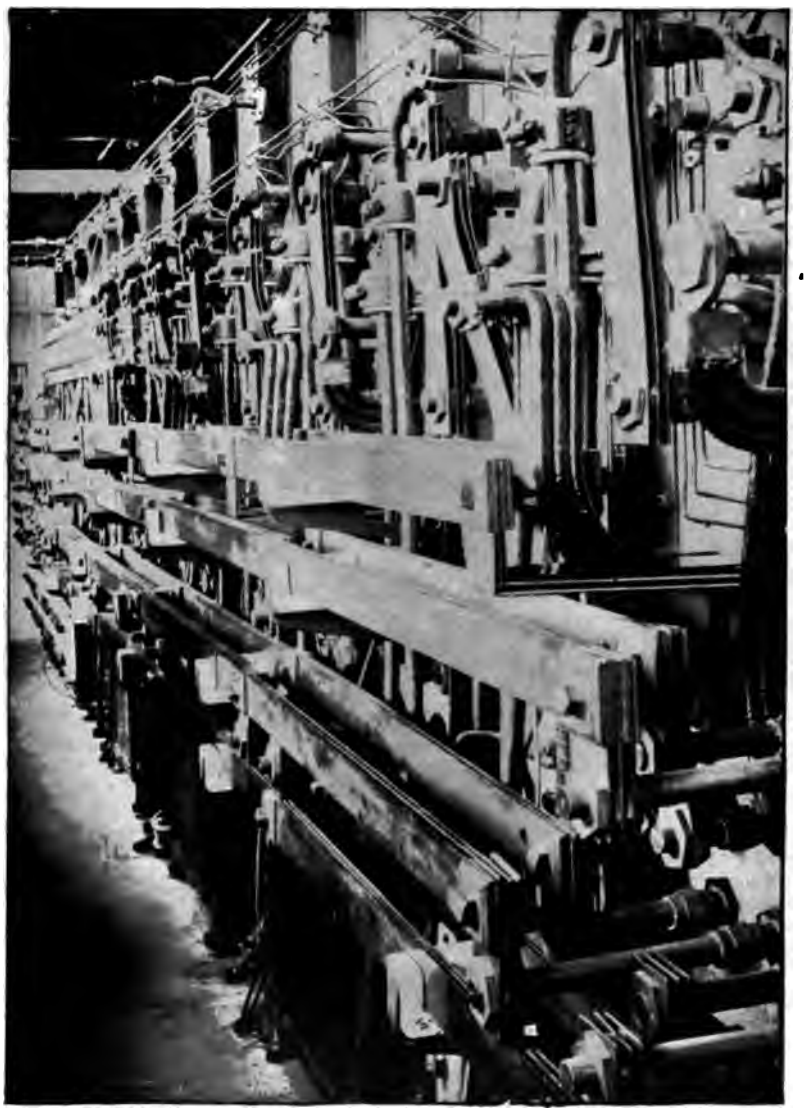


FIG. 183.—REAR VIEW OF MAIN SWITCHBOARD.

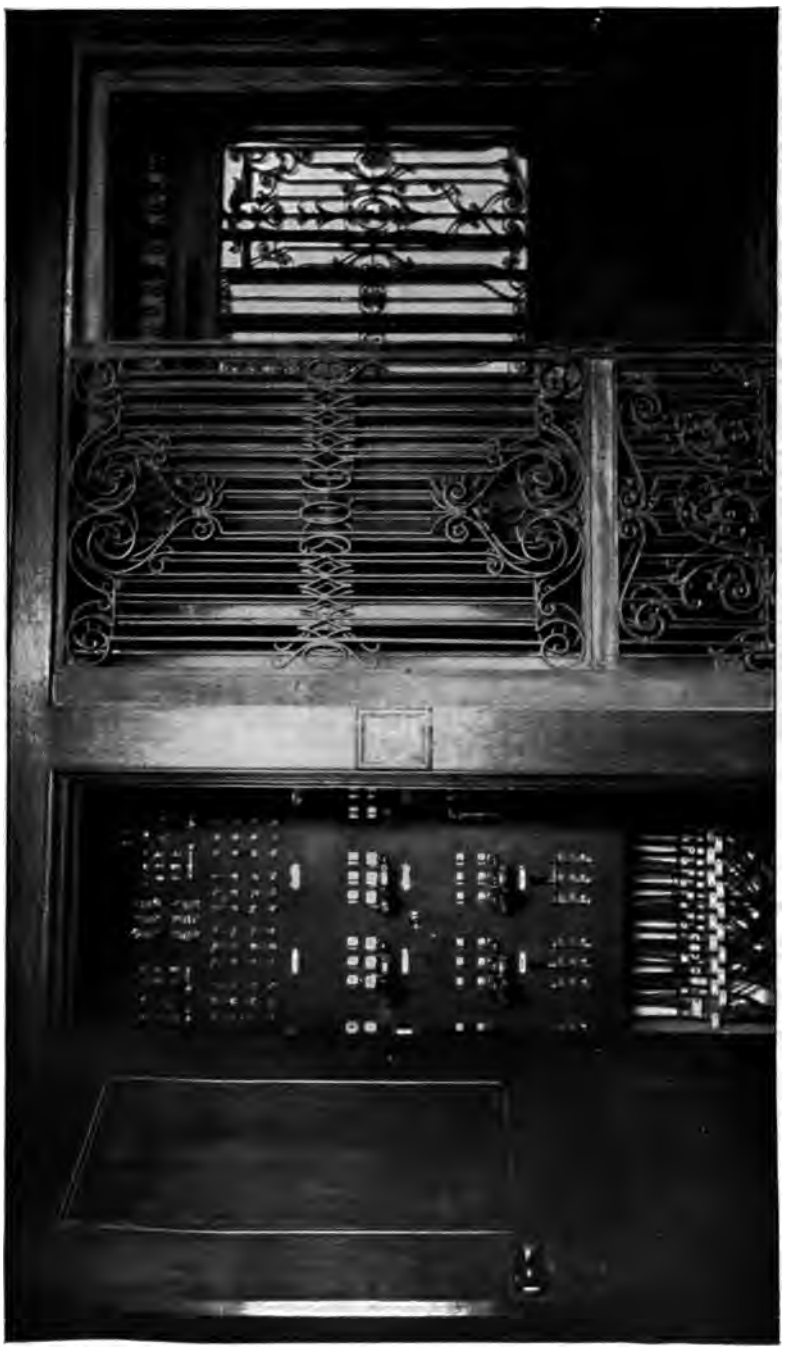


FIG. 184.—GLIMPSE OF DISTRIBUTING CENTRE NO. 1, CONTROLLING PUBLIC LIGHTS IN HEAD HOUSE. VIEW SHOWS ONE OF THE ELECTRIC PASSENGER ELEVATORS AT THE RIGHT. (SEE ALSO FIG. 212.)

FIG. 185.—INTERIOR OF HEATING CHAMBER NO. 5, SHOWING ELECTRIC TRANSMISSION OF POWER.

a frontage of approximately 2,200 feet. A loop circuit was also used for the attic fan motors and for the elevator motors.

All distributing boards and cut-out boards are of slate, enclosed in slate-lined cabinets and boxes. High grade triple or double pole, double break, jack-knife switches are used, and lugs are extended through boards for back connections. Except in case of the cut-out boxes, all bus bars and wiring connections are on back of boards, and means are provided for making all connections easily accessible. Meter connections are provided in all cabinets and boxes supplying lights to restaurants, barber shop, kitchen, and other premises subject to lease.

The maximum loss of potential between distributing centre and lights was not allowed to exceed 5 per cent. with all lights burning, and no more than 2 volts difference between any two lamps fed from the same centre under any conditions of load.

Cast-iron outlet boxes are installed at all outlets in the concealed work, and provided with substantial fixture supports. Similar boxes are also used for all switch outlets. With few exceptions, the incandescent lamps are 16 candle-power, high efficiency, and arc lamps are of the enclosed type, all lamps operating on a difference of potential of 110 volts. Wherever wiring work is installed in damp places, waterproof construction has been employed.

Railway terminal lighting includes practically every class of service from the occasional basement or attic incandescent to the brilliant waiting-room illumination, including office lighting as well as corridors and service rooms, stairways, restaurants, and baggage rooms, trainmen's house, power houses, signal towers; while the train shed, platforms, midway, carriage concourse, sidewalk, and yards call for an extensive and varied arc-lighting service.

The motors connected number 48 and aggregate 698 horsepower, the largest size being 50 horse-power. They are for the most part 220-volt shunt-wound 4-pole machines of standard pattern. The elevator motors are a noteworthy exception to this, as are likewise the vertical shaft motors for exhaust ventilating fans, and also for the sump pumps, all of which special machines are herein elsewhere described. The motors are as follows:

	Motors.	Horse-power.	Total Horse-power.
For sump pumps	1	10	
	1	30—	40
For elevator machines	6	20	
	15	15	
	3	12—	381
For heating and ventilating fans	2	5	
	2	15	
	1	20	
	1	30	
	5	1	
	1	0½	
	4	4½	
	1	8	
	1	0¾—	122¼
Roll lift drawbridge	3	50	
	1	5—	155
Total	48		698

Heating and Ventilating.

At the outset, two restricting conditions were imposed on the heating and ventilating system. These were, first, that all heat, so far as possible, should be indirect, and, second, that no pipes should be placed above or within 50 feet of either side of the main waiting-room ceiling. Besides these, there were other limiting factors due to certain features of the buildings and the power service, such as great length and small width of the head house and baggage wing; a very large cubic contents (nearly 5,000,000 cubic feet) with a relatively large exposed surface; insufficient and almost inadequate space for suitable size air ducts except for a hot blast system; a nearly complete severing of the building into two nearly equal parts by the main suburban exit with its floor of waterproofing which could not be sufficiently altered to provide passageway for large pipes; and variance in demand for heat and supply of exhaust steam in point of time and quantity.

Designs and estimates were made in connection with Prof. S. Homer Woodbridge for the following four systems, each based on a partial or complete plan of indirect heat:

First. A hot blast system using exhaust supplemented by live steam in stacks, and delivering hot air by blower fans over these to the rooms through the system of air ducts originally provided in the building plans. Removing foul air through vents and

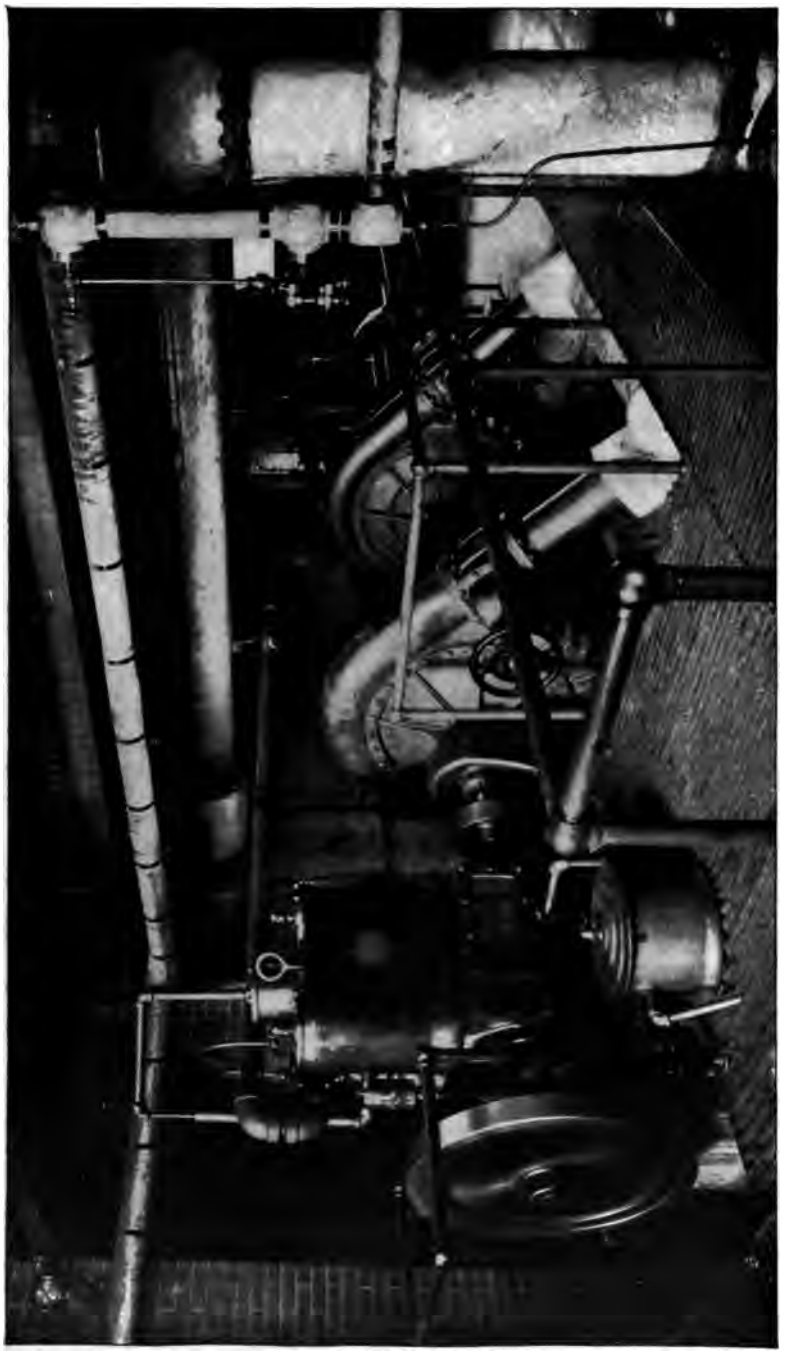


FIG. 186.—HOT WATER CIRCULATING PUMPS, CENTRAL HEATING PLANT. LOCATED IN BASEMENT ROOM, BETWEEN BOILER HOUSE AND ENGINE ROOM.

ducts and discharging above roofs by means of exhaust fans located in attics.

Second. A hot blast and tempered air system supplemented by direct steam radiators in many rooms. In this, the ducts designed for foul air were utilized for tempered air, and the waste spaces around ducts were utilized for exhaust ventilation.

Third. A direct hot water heating system using tempered air for ventilation, doing away with one system of air ducts and utilizing waste spaces around supply ducts for removing foul air.

Fourth. A part indirect hot and tempered air and part direct heat system similar in some respects to No. 2, but using hot water instead of steam.

The first and second were excessive in cost. They required very large and extremely long exhaust steam mains, also difficult and expensive provisions for handling returns. They were also comparatively uneconomical in the use of steam and deficient in certain special sanitary requirements.

Plan No. 3 was the most efficient as well as the least expensive, but involved the use of direct heat to a much greater extent than was permissible, and was abandoned in favor of the fourth system, which best met all requirements.

Hot water was chosen for the circulating medium only after a thorough study of the possibilities and limitations in the use of both steam and hot water. This made it evident that a hot water circulating system in the form of a loop with return mains in transverse subway not only overcame all physical difficulties encountered in the problem of distribution, but, under the rather unusual conditions which surrounded the heating plant, was superior in every respect. The rapid circulation secured by the use of pumps made all points in the system equally accessible and easy to heat. The amount of water necessary to supply the heat required could be conveyed in a flow main no larger than 8 inches in diameter, and without difficulty due to unavoidable pockets at certain points; notably at the main suburban exit.

Owing to the storage value of the large body of water contained in the system, the surplus of waste steam at periods of heavy load could be absorbed, within limits, for use when there might be a deficiency of exhaust at times to reduction of load, and be utilized to a greater extent than possible by other methods. Furthermore, while all heating apparatus must be adequate for the severest weather conditions, the hot water system possessed

FIG. 187.—VIEW SHOWING HOT WATER HEATERS IN CENTRAL HEATING PLANT.

the considerable advantage of being capable of operating at lowered temperatures corresponding to mild or moderate weather, thus preventing waste and discomfort from overheating and undue radiation and leakage losses.

The water is circulated by one of two 8-inch centrifugal pumps, each driven at a speed of about 375 revolutions per minute by an 8½ by 8 Westinghouse Standard engine. The water reaches the pump suctions through the 8-inch return main by way of the transverse subway, and is delivered to the supply side of the system, after becoming heated to a suitable temperature in a central heating plant located near the circulating pumps in the power house. This consists of three specially designed heaters, two being for exhaust, and a third and smaller one for the use of live steam whenever there may be an insufficient supply of exhaust. Two exhaust heaters were used largely because of the inexpediency of installing a single heater of large dimensions, and partly on account of the advantage of having the principal part of the heating plant in duplicate. There was also advantage in regulation, by subdivision. The exhaust-steam heaters are capable of condensing 24,000 pounds, and the live-steam heater approximately 18,000 pounds steam per hour, live steam being admitted to the heater only to supply deficiency, the quantity being regulated by an automatic thermostat valve.

The heated water passes from the central heating plant into the flow main and to the exterior circuit, which forms a loop over five-eighths of a mile in length. This entire system, in which there is necessarily a large amount of expansion and contraction, contains no expansion joints, the design of the piping and the free use of long radius pipe bends permitting the strains due to expansion to be taken up without imposing undue stress on fibre or joint. All turns in the flow and return mains were made by these bends, no elbows being used, thus materially reducing the circulating head, which would otherwise have been excessive except larger and more expensive mains were provided. The engineering problem involved in the proper design, support, and anchoring of these hot water mains was not the least interesting of the several somewhat unusual features of the work. In this connection, it is interesting to note that the actual circulating head proved to be within 2 per cent. of the estimated amount.

Branch connections are made from the mains to five indirect heating chambers, besides many risers and drops connecting with

FIG. 188.—PIPING AND FEEDER WIRING IN DORCHESTER AVENUE BASEMENT. LOWEST PIPE IS 8-INCH FLOW MAIN HOT-WATER HEATING SYSTEM. VIEW SHOWING METHOD OF CARRYING PIPES AND WIRES UNDER STAIRWAY.

FIG. 89.—INTERIOR OF HEATING CHAMBER NO. 3. THIS IS THE LARGEST OF THE FIVE HEATING CHAMBERS. THE PAIR OF LARGE FANS IS DRIVEN BY A 30 HORSE-POWER MOTOR, AND SUPPLIES AIR TO A LARGE SECTION OF THE OFFICE BUILDING. THE SMALLER FAN AT LEFT FURNISHES AIR TO THE MAIN WAITING ROOM EXCLUSIVELY.

direct radiators, and the entire piping system is thoroughly covered with non-conducting material. The heating chambers are located at various points in the basements of the head house and baggage wings, and contain the necessary primary heating stacks to temper the air supplied to the building for ventilation. In three of the chambers supplementary heaters are provided for further heating the air required for indirect warming. These chambers are air-tight, and each receives fresh-air supply from above the roofs through vertical intake airshafts. In every case the fresh air is tempered to about 70 degrees, and delivered directly or indirectly by means of suitable blower fans through extensive galvanized iron ducts to the various rooms in the building.

All occupied portions of the buildings are ventilated with a degree of thoroughness seldom found except among such buildings as the best type of modern schoolhouses. This ventilation is constant and is secured quite independently of the means provided for warming; the tempered air contributing little to the required supply of heat. It is worthy of note that a building devoted to railway and office uses, and built on such an extensive scale, should have such excellent and profitable provisions for the health and comfort of public and employees.

The blower fans are driven by electric motors. They supply to the ventilated portions of the building sufficient air to equal their volume every 15 to 20 minutes. A portion of the tempered air supply is diverted from the fan-discharge ducts and is passed through the supplementary heaters, where its temperature is suitably raised for supplying heat to those portions of the building warmed wholly by the indirect method. The hot air is carried in a separate system of ducts, which parallel the tempered air ducts, to points where it is delivered to the various rooms. Specially designed mixing dampers are provided for controlling the proportions of hot and tempered air supply. The use of these mixing dampers is such that the total quantity of air supplied is not altered; their office being to regulate the relative amounts of hot and tempered air, and thus the temperature of the mixture supplied at each inlet. In this way the supply of heat can be increased or diminished without affecting the sufficiency of ventilation.

The form of building, its unusual proportions, and space restrictions made the matter of air distribution rather a difficult one, and necessitated an extraordinary tightness in the air ducts, especially

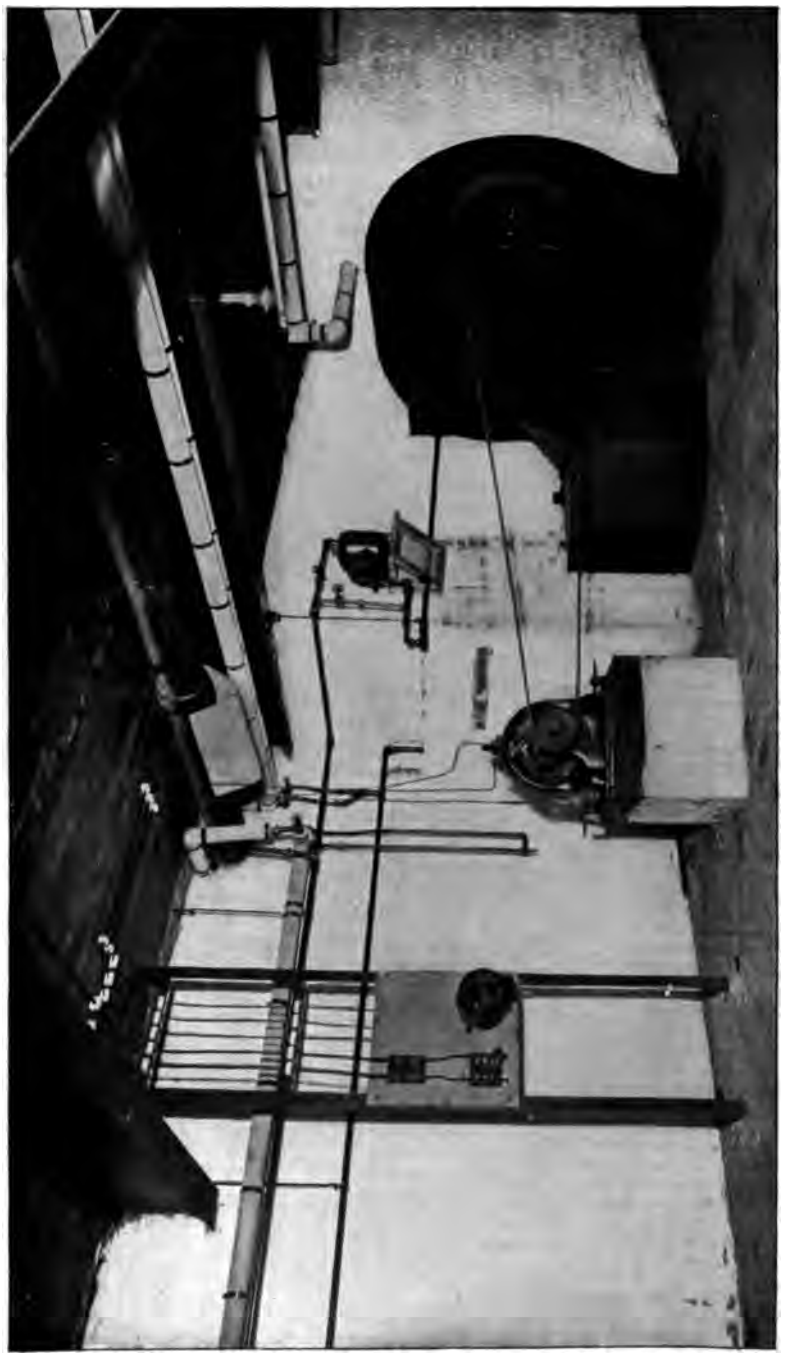


FIG. 190.—HEATING CHAMBER NO. 6. IN THIS CASE THE FAN IS OUTSIDE, AND IS DRIVEN BY A 5 HORSE-POWER MOTOR. TEMPERED AIR ONLY IS SUPPLIED FROM THIS CHAMBER.

as the use of the spaces around the supply ducts for exhaust ventilating flues would have made any considerable leakage a matter of consequence. The unavoidable shape of the ducts, their great length, and the opportunity for excessive heat wastes into the dis-

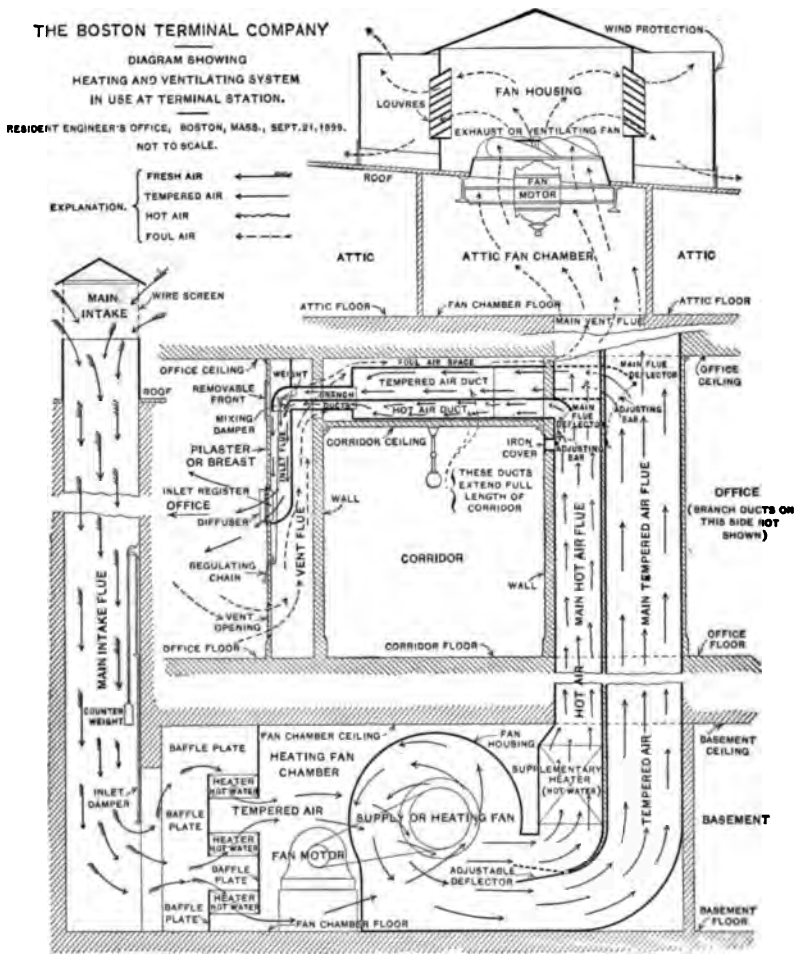


FIG. 191

charging air, made it necessary to cover the hot air supply system with non-conducting material in order to enable the hot air to reach the more distant outlets at nearly full temperature. Asbestos sea-weed quilt (Cabot's) was used for the work and served its purpose well, although the difficulties in applying any insulating

FIG. 192.—72-INCH EXHAUST VENTILATING FAN LOCATED IN ATTIC FAN CHAMBER, SHOWING 8 HORSE-POWER SPECIAL MOTOR AND METHOD OF SUSPENSION FROM ROOF BEAMS.

material were considerable. This arrangement was undoubtedly the best that could be employed under the conditions, although simpler means would have been used had they been permissible.

The ventilation of the building is assisted by 11 electrically driven exhaust fans, which are located in corresponding attic fan chambers, and which withdraw the vitiated air from the building through the waste spaces around the air-supply ducts, discharging it above the roofs. The motors by which these fans are driven are of special design, with vertical shafts, and are dust proof.

The fan wheels are mounted on the upper ends of the shafts, and the motors are in all cases supported by the roof structure. All portions of the air-circulating system are made fireproof.

Direct heat is used in baggage rooms, corridors, and all places where ventilating is not required, and also in certain portions of the building where it was not considered feasible to heat wholly by the indirect method; full ventilation being secured in such instances, however, by tempered air. Direct heat was also used in all lavatories, for sanitary reasons. In all cases these lavatories are adjacent to rooms supplied with fresh air under slight pressures, except in one or two instances, where the entrance is from outside the building, and the air movement is thus always into these rooms from the surrounding spaces. Exhaust ventilation is provided by a separate system of ducts and ventilating fans having no connection with the main ventilating apparatus. The fixtures are vented into air-tight chambers connected with the discharge ducts, the only outlet being through these vents, and a free movement of air is thus assured not only towards such rooms, but into and through each fixture. The contrast between the air in these rooms and in the ordinary railroad lavatory is very marked.

The express building is warmed entirely by direct heat, no ventilation being provided. This building is served separately from a loop of the main heating system, having its origin and return near the central heating plant in the power house. The interlocking towers and yardmaster's building are heated by direct steam supplied from the car-heating system.

Disposal of Drainage from Waterproofed Structure.

The disposal of water from the large area of waterproofed structure required means for pumping, owing to the fact that a

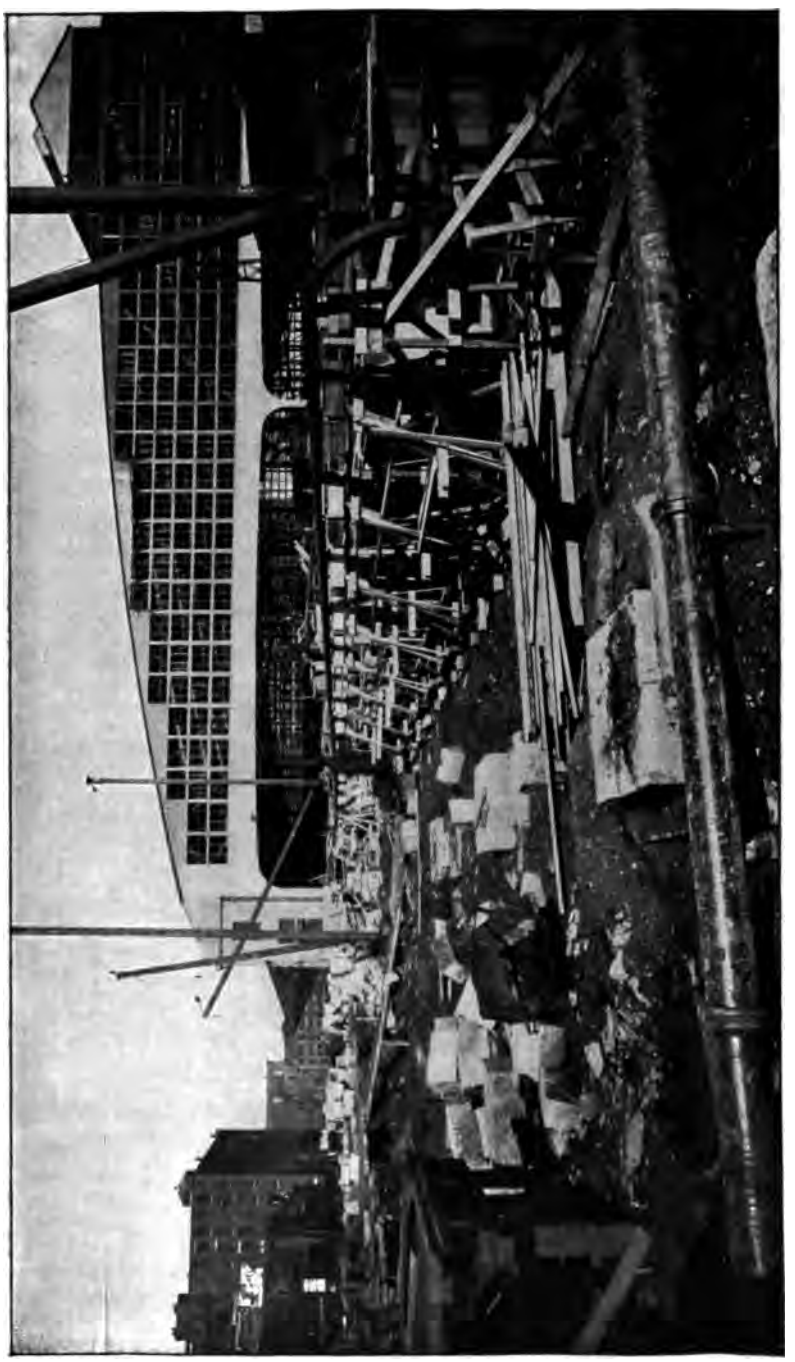


FIG. 193.—PORTION OF 8-INCH HOT-WATER RETURN MAIN TEMPORARILY SUPPORTED IN PERMANENT POSITION IN WHAT WAS AFTERWARD BASEMENT OF EXPRESS BUILDING. PIPE ENTERS WESTERLY END OF TRANSVERSE SUBWAY, WHERE IT TURNS DOWN AND TO THE RIGHT. THE BUILDING WAS HEATED THROUGHOUT THE WINTER OF 1898–99 WITH RETURN MAIN IN THIS CONDITION.

large portion of the basements and all of the suburban loops are some 7 or 8 feet below water level in the bay at high tide.

In considering the drainage of this large area, it was necessary to take into account the possible seepage, the probable quantity of storm water, and to provide sufficient pump capacity to handle both at time of flood tide. There was no way to predetermine the seepage, although a pumping capacity of 1,000 gallons per minute was considered more than ample to handle any probable amount of water which might find its way to the pump from this cause.

The question of storm water was capable of more exact treatment, as in the latitude of Boston the rainfall seldom exceeds 3 inches per hour, and never for long enough periods to cause more pumping than such fall would require. The area exposed to storm water is approximately 91,240 square feet, and upon this surface it was estimated that 171,759 United States gallons of water might fall per hour at a 3-inch rate. It was assumed that about 25 per cent. more water would be driven from tops of retaining walls, surrounding embankments, yards, etc., making a total of 214,698 gallons as the total maximum quantity of storm water to be pumped per hour. This gave 3,578 gallons per minute, and an 8-inch centrifugal pump was chosen, capable of discharging 4,000 gallons per minute under the conditions of head and speed imposed.

It was not considered that snow and rain could swell the total to an uncontrollable amount, for the presence of snow and ice would retard the flow sufficiently to check the speed with which the water from a heavy downpour would reach the pump, and in general it was concluded that the natural resistances to water-flow would prevent accumulation at the well faster than could be handled by a 4,000-gallon pump.

The use of two pumps was regarded as essential for service as important as this, in order that one might relay the other. A single pump, if disabled, would be flooded, and could not be reached for repairs. By dividing the pump capacity unequally, and arranging the smaller pump to deliver its full capacity of 1,000 gallons per minute against a 16-foot head (the most extreme condition), and the large one to deliver its full rated capacity of 4,000 gallons per minute against a head of 13 feet 6 inches, and a correspondingly smaller quantity against heads up to the maximum of 16 feet, the larger pump was enabled to work to its fullest

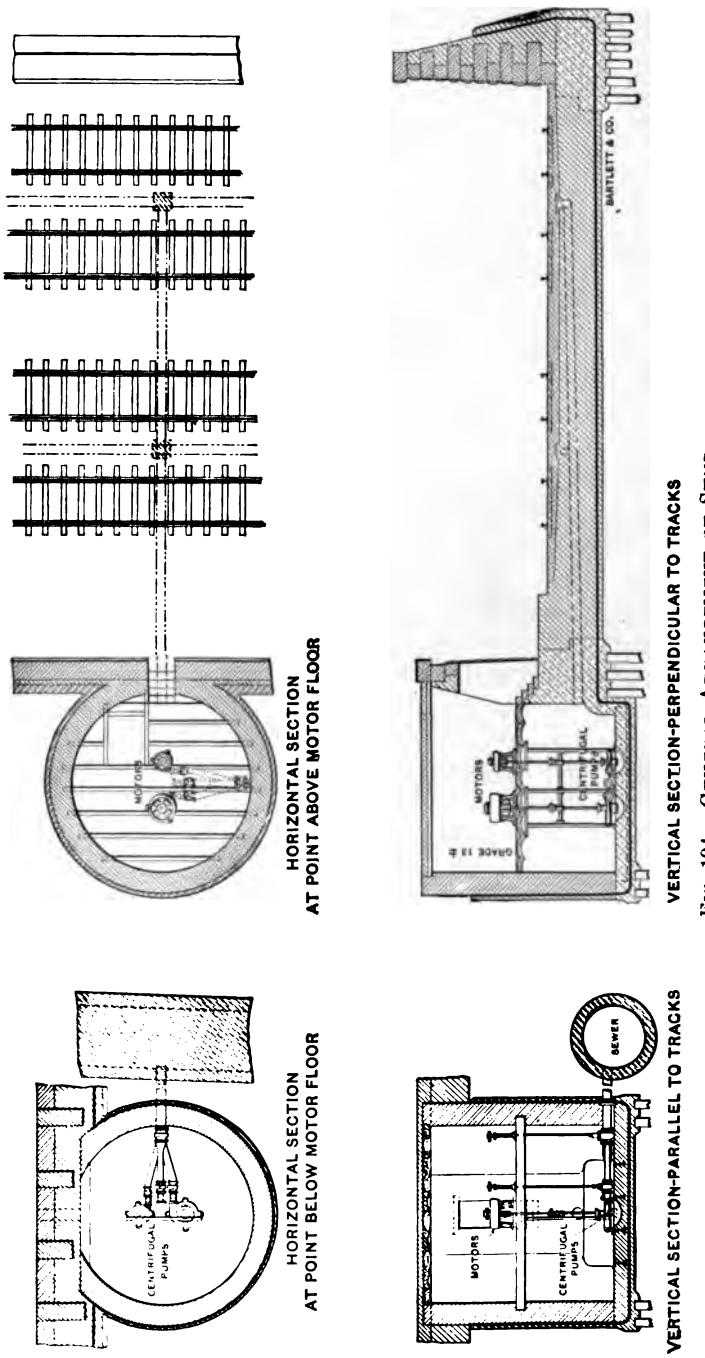


FIG. 191.—GENERAL ARRANGEMENT OF SUMP.

capacity and best efficiency against amounts of water that would accumulate in the sump more than 2 feet 6 inches deep. The smaller, or seepage pump, works to its full capacity against the entire 16 feet required at times of extreme high tide; thus giving this pump as long a period of operation as possible, and avoiding the undesirability of too frequent stops and starts. Seepage waste and ordinary storm water is therefore handled by a very moderate size light running pump, which does nearly all of the work required, while the storm pump is preserved for emergency work and relay. Both pumps are electrically driven, and each has a special vertical Westinghouse motor coupled directly to the upper end of its shaft. The pumps are submerged, and discharge through suitable check and gate valves into an adjacent sewer. When the accumulation of water is sufficiently small, the check valves act as tide gates, and allow the water to discharge to the sea at low water without the aid of the pump. Provision is made in the design and arrangement of piping, valves, and connections, for the installation of a third pump should its use at any time be required. Considerations of corrosion, electrolytic action, and life of materials led to the choice of cast-iron cases and bronze running parts and bolts for all submerged work. The shafts and bolts are of Tobin bronze. The weight of motor armatures and other moving parts is carried on suitable thrust bearings located between the pumps and motors, and supported on structural work provided in the sump for the purpose.

The small pump is arranged to start and stop automatically by the rise and fall of the water in the sump, through the use of suitable controlling devices actuated by floats. The ordinary work of pumping therefore takes care of itself, and little or no attention to the operation of the machinery in the sump is required. A high-water indicator is also provided, and connected with a loud ringing gong in the power house, to give alarm in case the water should accumulate above the higher limit handled by the small pump; the arrangement being such that the bell will ring constantly and alarm the power-house crew if the water stands at or above a predetermined danger level. The large pump is started and stopped by throwing a jaw switch by hand in the usual way.

The walls of the sump well are built of brick, and the roof and floors of iron and masonry. The motors and controlling devices are located on the upper of the two decks, and the pumps at the bottom of the well, the lower chamber being reached

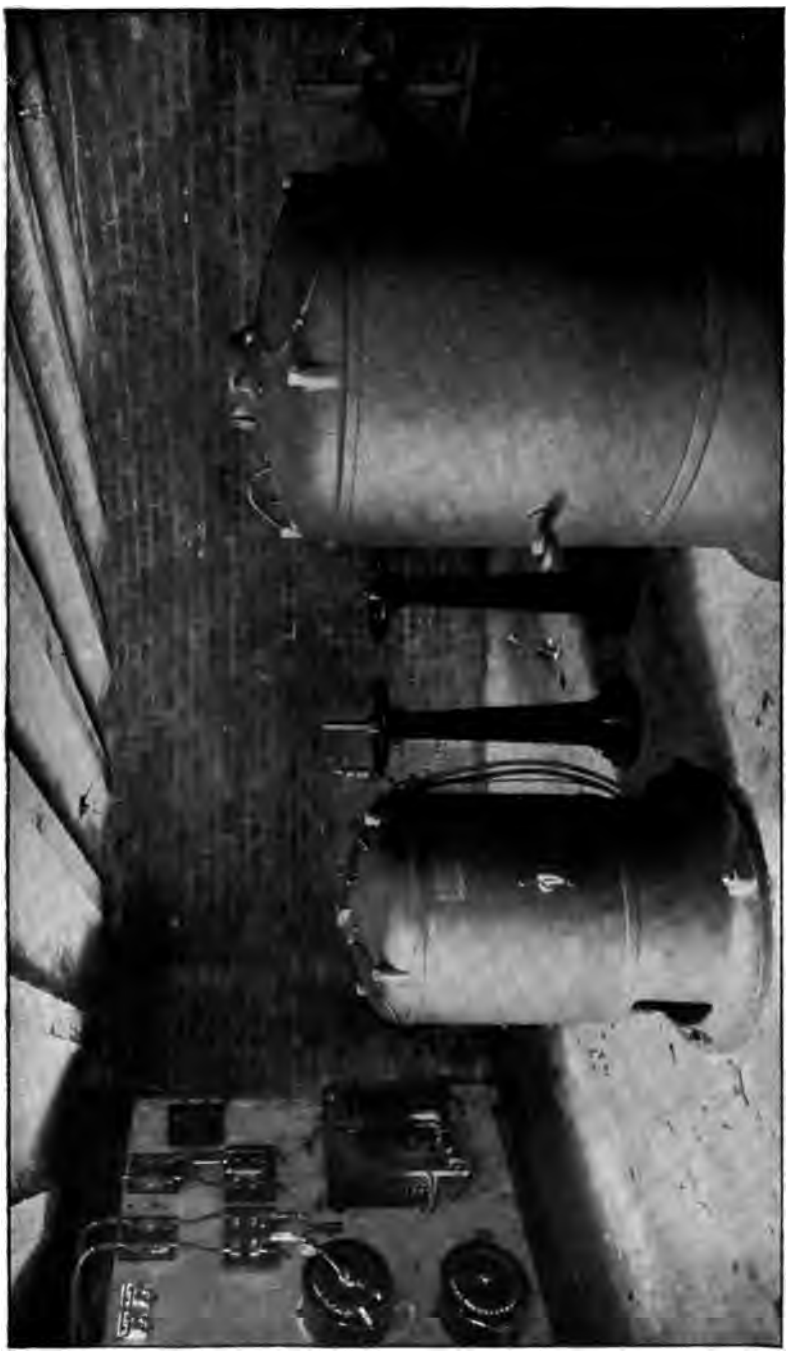


FIG. 195.—INTERIOR OF UPPER CHAMBER IN SUMP. THIS WELL IS TWENTY FEET IN DIAMETER, AND PUMPS ARE LOCATED IN CHAMBER BELOW THE ONE SHOWN. VIEW SHOWS SPECIAL MOTORS WITH VERTICAL SHAFTS, AND SWITCHBOARD WITH CONTROLLING APPARATUS.

through a trap-door by means of iron stairs and platforms. The well is lighted by electricity, and the upper chamber warmed by steam to prevent excessive deposition of moisture from the atmosphere on the otherwise cold surfaces.

The sump is located near the power house, with entrance in the side of the easterly retaining wall of the depression for the suburban loop tracks; and all portions of the waterproofed area, which aggregate several acres, are connected with the well by half-section tile drains, imbedded in the concrete under the stone ballast.

The operation of the sump has been exactly as contemplated, and satisfactory in every respect, the only emergency so far met being a considerable and unexpected quantity of water driven, during a heavy storm at an extreme high tide, over the top of some sheet piling used in connection with construction work.

Roof Drainage.

One of the more unusual problems met in the work was in connection with the drainage facilities for the large train shed and head house roof areas, aggregating about twelve and a half acres. The climate of Boston is particularly unfavorable to roof drainage on such a large scale, the variable temperature causing alternate thawing and freezing, thus conducing to blocking gutters and bursting leaders. The arrangement of valleys and adjacent windows was such that it became absolutely necessary to carry away water at all times and under all conditions and also to prevent the undue accumulation of snow and sleet in the principal valleys.

There were some two dozen copper or cast-iron leaders varying in size from 6 inches to 12 inches in diameter, and some were over 600 feet long. All were to be exposed to severest freezing weather—most of them throughout their entire length—and in many cases there were of necessity long horizontal runs. Nowhere could any method be found in use where such conditions were being met with even partial success; the difficulties at the Northern Union Station in Boston, the most analogous case, being particularly troublesome.

A consideration of all the conditions to which such drainage is subject led to the conclusion that it was useless to attempt any extensive thawing of snow or ice on the roofs, and that whatever expense might be incurred should be concentrated principally upon the leaders to keep them clear at all times, in order that whatever water might result from rain or melting snow would not accumu-

FIG. 196.—MAIN CROSS-OVER IN APPROACHES TO SUBURBAN LOOP. POWER HOUSE TO RIGHT OF VIEW, AND PIPE BRIDGE FORMING PART OF TRANSVERSE SUBWAY AT LEFT. DOOR IN RETAINING WALL, NEAR BARRELS, IS ENTRANCE TO SUMP. THE OBJECT AT UPPER RIGHT-HAND CORNER OF VIEW IS POWER-HOUSE STACK, NOT A WATER TANK.

late in the valleys, but always find channels of escape. Nothing further than this, except means for keeping an open channel in one of the principal gutters, has been found necessary, and during the severe winter of 1898–99 the means provided were found adequate.

Of the several methods devised, a most practical one proved to be the one finally employed. It consisted in jacketing each of the principal leaders with heavy wire lathing and an inch of asbestos sponge, with an air space of about one and a half inches between the jacketing and the leader pipes. This jacketing was constructed in a very substantial manner, supported every two feet on heavy wrought-iron clamps, and all covered with heavy canvas sewed on tightly and thoroughly painted. The jacket space on each leader is kept warm in the most extreme weather by a single run of 1-inch steam pipe with its return, the entire system being conveniently connected with the car-heating mains.

Provisions were made in some instances by the use of suitable U traps in the basements to seal the lower ends of the leaders against undue air circulation.

As compared with the usual method of melting snow, the use of steam for keeping the jackets warm and the leaders above freezing point is small. The warmest spots in the roof are at the mouth of each leader, and these are consequently comparatively open, thus facilitating drainage toward the outlets. In only one instance, namely, the valley between the midway roof and the head house, has it been found necessary to make additional provisions for handling snow and slush; but in this case the valley is so large and shallow that it has been found necessary to facilitate the flow of water to the down spouts, and a single run of 2-inch brass pipe has been provided for the purpose. This may be used to a limited extent for melting snow if desired; but is intended primarily to keep the gutter open, and thereby greatly increase the opportunities for melting snow to filter through the slush and flow to the outlet points.

The use of steam, in addition to the protection afforded by the jackets, is seldom required; but during the few days when used last winter the results were good.

Ice-making, Refrigerating, and Water-cooling Plants.

A problem requiring careful study was how best to meet the needs of the new station for an efficient and economical service

FIG. 197.—INTERIOR OF TRAIN SHED, SHOWING SEVERAL OF THE COMPLETED ROOF LEADERS AT SIDES OF TRAIN-SHED COLUMNS.

for all purposes requiring cooling work. These included the cooling of drinking water for passenger cars of all descriptions, as well as chilling the refrigerators of dining cars; the filtering and cooling of drinking water for public waiting rooms and corridors and for offices and restaurants throughout the buildings, and the chilling of cold storage rooms and kitchen boxes used for restaurant and florists' business. Unlike the several other operating departments of a large railway terminal which are, of necessity, items of direct expense, ice-making and refrigerating service offered opportunity for substantial earning power. While similar cooling is often done wholly by the melting of ice purchased or made for the work, it was recognized that much of the expense, dirt, and annoyance incident to the old method could be obviated by the use of mechanical refrigerating processes.

The superiority of mechanical refrigeration over the use of ice for restaurant refrigeration was very evident. Its use would secure lower temperatures in storage boxes; a greater percentage of space available for storing goods; dry air in boxes with the resultant ability to store goods indefinitely, instead of a wet atmosphere and slimy boxes; reliable and uniform cooling instead of temperatures varying as the ice melted away; less operating cost for the service by using a much cheaper cooling medium, and by saving all labor in ice handling; and increased rental value of restaurants. In the general investigations that were made of other railway terminals, it was ascertained that the use of artificial ice and mechanical refrigeration is very common in the more important stations, except in the northwest, and is much preferred on any basis of price. Except in Chicago, it was found cheaper to manufacture than buy the natural ice. Restaurant refrigeration, where done with ice, either manufactured or natural, was invariably condemned as inconvenient because of foul, wet boxes. The data which were secured revealed, among other things, the facts (1) that the three railroads using the new terminal consume less ice per train per day, or make more runs on one icing, than at other large terminals, due to large suburban traffic and lower summer temperatures; (2) that smaller weights of ice are used per car, but more cars are iced per train handled.

The probable ultimate ice and refrigerating load for the terminal was ascertained after a close study of the needs and methods of other large railroad stations. The maximum monthly and total yearly requirements for all purposes were determined, and a close

relation established for the maximum, minimum, and mean ice consumption throughout the year. From a yearly load curve plotted from this data, the requisite ice storage to equalize the excessive consumption of the four summer months was fixed at 800 tons, this storage space being provided under the ice-freezing tank.

A nominal daily capacity of 20 tons of plate ice was selected as best meeting the conditions, which, with the ice storage provided, makes 26.5 tons of ice available daily for four hot-weather months, in addition to the refrigerating and water-cooling loads. These other gross loads were similarly found, and the sum of all determined for maximum load conditions.

For the commercial manufacture of this artificial ice there were two general methods available, commonly known as the "can" and the "plate" systems.

In making ice by the can system, galvanized iron cans containing the water to be frozen are immersed in a brine bath maintained at a low temperature by submerged cold ammonia expansion coils. The water is frozen *inwardly*, and any air or impurities existing in the water are, of necessity, frozen into the centre, or core, of the ice block. To so make clear ice, it is therefore essential to use distilled water, carefully filtered and purified.

In the plate ice-making process, the plant is simplified by submerging the cooling, or freezing coils directly in the fresh water to be frozen and allowing the ice to form on the outside of these coils, from which it is then cut. The water is frozen *outwardly*, excluding the air and impurities into the residual unfrozen water.

The complex, intersecting crystalline structure of can ice (frozen from all sides) and its softer core, result in a so-called "rotting" of the cakes unless stored in a temperature below 32 degrees, and makes storage unsatisfactory. The cost of distilling and purifying the water is also large as compared with the plate system.

The direct ammonia expansion plate system is much simpler; has fewer purifying and freezing processes, and the character of the ice product is denser, clearer, without core or other impurities, and has much better storing qualities than ice frozen in cans, and was considered superior in every way. For all these and other reasons the plate system was preferred, and a plant using the anhydrous ammonia compression system, as built by Westinghouse, Church, Kerr & Co., was installed.

The ice-making plant being the largest, and in some respects the leading, feature of the mechanical cooling system, had a determin-

ing influence on the design of the balance of the refrigerating work. All water cooling and all the refrigerating work, except the chilling of the ice-storage cellar, was to be done in the head-house building, at distances varying from 1,000 to 2,000 feet from the power house building. To properly transmit these long distances without undue losses was an important consideration in the design of the plant. Both the direct ammonia expansion and brine circulating systems were available for this work, with some advantages in favor of both. First cost, conditions of operation, character of the service, and temperatures to be held, were the leading factors in the selection for this service. Direct expansion cooling was the cheapest, and would give lower temperatures and greater refrigerating capacity with the same compressor displacement than the brine system; but very low temperatures were not required, and the slight saving in power and first cost were more than overbalanced by substantial advantages in operation and control, secured by the general use of brine circulation under the set of conditions met at the station. These considerations did not apply to the water-cooling service, however, and direct expansion was accordingly employed for that work.

The three principal divisions of the terminal cooling plant—namely, the ice making, refrigerating, and water cooling—are but separate parts of one general system, taking power from the common high-pressure steam supply of the power plant. They are, of necessity, closely related and are grouped together, although independently operated outside of the engine room of the ice and refrigerating building.

The size and design of the ice and refrigerating room, and the general arrangement of machinery, are shown in the accompanying illustration. The plant is located on north end of power-house building adjoining the engine room, but isolated therefrom by a brick partition, built as high as passageway for the overhead engine room crane would permit. This crane is arranged to handle any part of either ammonia compressor as well as the machinery in the engine room.

A photograph taken from floor level and from upper left-hand corner of plan view of this room shows the two ammonia compressors. Both cuts show the ammonia condenser and ice-making tank. These were placed in upper portion of building to permit of storing 800 tons of ice in the insulated cellar space, there being no other room available for the purpose. This ice storage helps

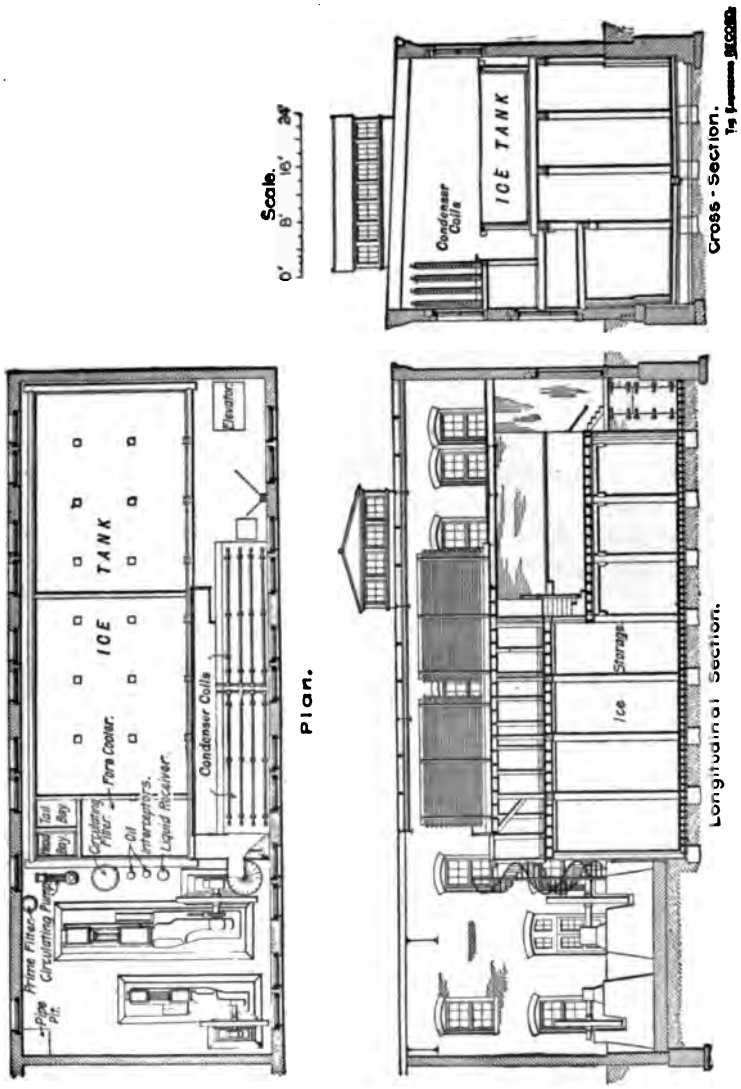


FIG. 198.—GENERAL ARRANGEMENT OF ICE PLANT.

to care for the excessive summer ice consumption; permits of uniform running conditions and smaller compressor capacity, and, in conjunction with the small compressor, provides ample relay machinery to insure continuous service. By placing this apparatus close to the power plant, a saving in operating labor is effected, and refrigerating transmission losses are avoided by using direct ammonia expansion cooling for the brine and water of the remote refrigerating and water-cooling plants in the head-house building.

Two ammonia compressors were installed, the larger being of sufficient capacity to handle the entire maximum load, while the smaller was made 50 per cent. larger than the combined maximum box refrigerating and water-cooling loads. Cylinder sizes are:

Steam, 20 inches by 32 inches, and 14 inches by 20 inches } double acting;
Ammonia, 16 " " 32 " " 10½ " " 20 " }

respectively for the large and small compressors. These compressors may be run with steam cylinders condensing or non-condensing. The compressors are especially designed for the handling of gas, either dry or carrying a large excess of liquid ammonia; *i.e.*, for either "dry" or "wet" compression, without any change in adjustment.

Horizontal compressors were used to secure ease of operation and safety by free discharge of liquid ammonia under the varying conditions to be met. Besides being strong and stiff under high pressures, this tandem Corliss machine shows less friction than other types, and the highest steam and mechanical efficiencies are therefore secured with the other advantages obtained. The ammonia cylinders have completely removable water jackets on sides, heads, and stuffing-box. Constant low temperatures of all working parts and increased gas displacement are thus secured. These compressors run on very nearly as small a clearance as is customary with single-acting machines, and secure another advantage commonly found only in the latter; namely, the packing of ammonia piston rods against low pressure only, by using a double-packed stuffing-box with oil chamber around rod between packings, which chamber is fed with oil under a slight head, and is also vented by a pipe connection to the suction or low-pressure side of system. This feature is not, however, peculiar to this machine, being used in a different form by some other builders. The results are excellent, as leakage of ammonia, hard packing, and cut rods are effectually avoided.

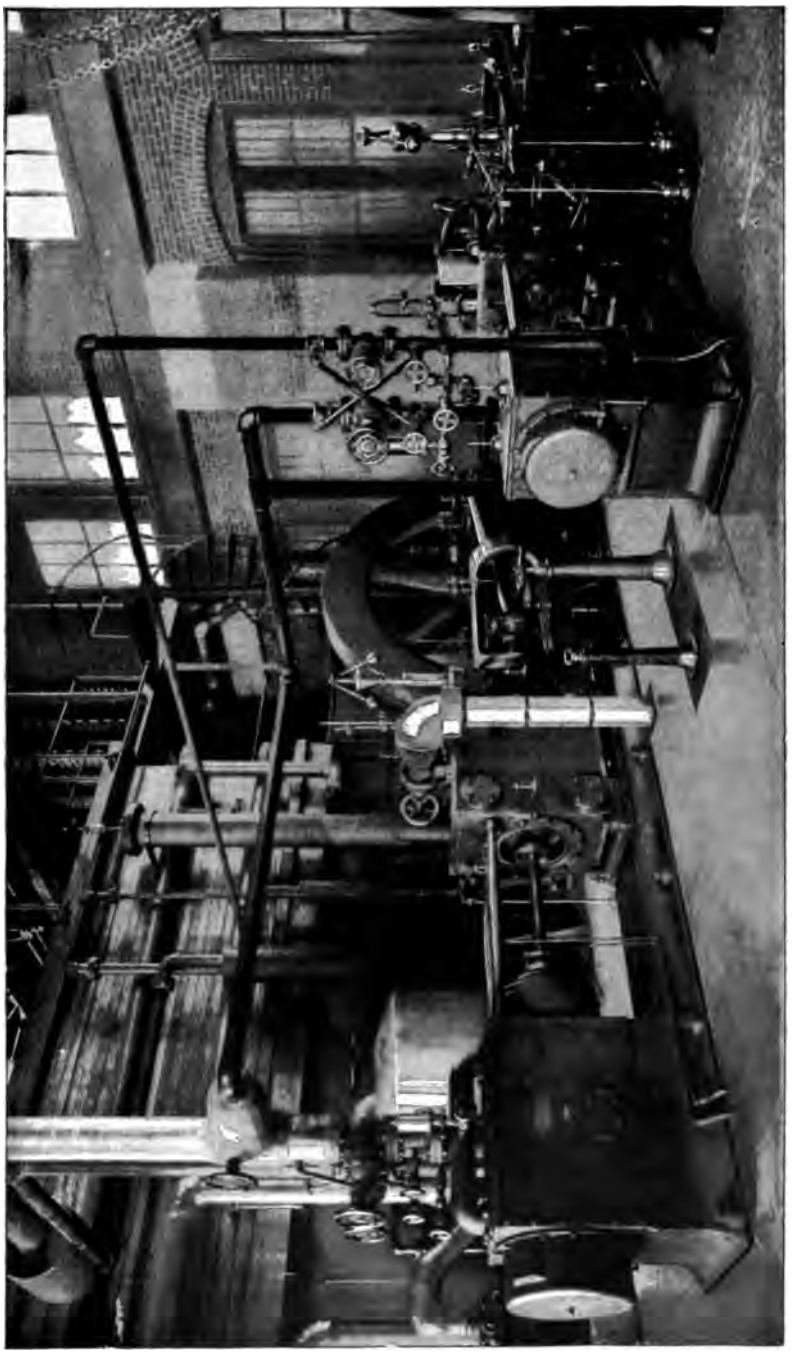


FIG. 199.—AMMONIA COMPRESSOR ROOM. ICE PLANT FREEZING TANK IN UPPER LEFT-HAND CORNER OF VIEW. AMMONIA CONDENSER IN BACKGROUND.

The ammonia condenser and top of freezing tank are shown in illustration. This condenser is of the sectional atmospheric style, of 2-inch extra heavy pipes 20 feet long and made up with extra heavy steel return bends, each connected by gas inlets and liquid-drain headers to its companion coils. Eight sections are used, each 24 pipes high. All pipes and fittings are heavily "Kalamined" to best resist the corrosive action of the salt water used for condensing purposes. This condensing water is fed to the coils from a heavy brass serrated trough placed over each coil section. Each coil may be isolated by closing its valves, and is provided with separate vents to atmosphere and to suction pipe to evacuate contents when desired. The Baudelot type of ammonia condenser, with initial hot gas cooling coil, placed under main condensing coil to extract the superheat from the gas entering condenser, was not used in this case, as the slight percentage gained figured so small that, with salt condensing water costing nothing except its pumping, simplicity and few condenser joints were deemed of greater value.

The freezing tank is made of heavy yellow pine framing, with 3-inch cypress lining, and is designed to make 20 tons of plate ice daily, from undistilled city water passed through an initial filter before charging into freezing tank. No brine is used. The freezing tank contains 6 feet depth of filtered fresh water, in which continuously welded, vertical coils of horizontal pipes are submerged. The freezing is accomplished by expanding liquid ammonia within these coils, causing the ice to form on the outside of coils. The ice, thickening as it freezes, extends sideways toward the plates of ice forming on adjacent coils. The coils are placed about 30 inches apart on centres, and the ice is cut therefrom when about 12 inches thick on each side of the coil. The ice on adjacent coils is not permitted to freeze together, and hence all the impurities expelled by the ice remain in the residual water, which is continuously circulated by a pump, between each pair of coils, entering at one side and overflowing on the opposite side of the freezing tank. This water is then drawn through a large deaërating quartz filter before being returned to the freezing tank, and the rejected, insoluble matter is thereby trapped and eliminated. Fresh water to replace the volume of ice withdrawn is automatically charged from city main into the forecooler tank, whence it is automatically fed by ball cock, into a tail bay, located in the suction run between freezing tank and circulating

FIG. 200.—TOP OF FREEZING TANK, SHOWING AMMONIA CONDENSER.

pump. The circulating pump discharges into the head bay compartment, from which the water flows by gravity through a pipe header along the front of freezing tank, and is discharged between each pair of coils, to be again similarly circulated. The incoming warm fresh water in forecooler is chilled by a pipe coil of generous area inserted in the ammonia-suction line to compressors, using the excess of liquid ammonia passing through the freezing coils for this initial cooling work. The harvesting of the ice from the freezing coils is done by steam cutters on the "block" system. These cutters consist of a frame mounted on wheels to run over tank covers, with a framework supporting vertical guides, and carrying a rectangular vertical knife frame of depth sufficient to reach to bottom of freezing tank. This knife blade has a small copper steam pipe secured to the lower edge. Flexible, insulated steam and drip connections are made to this moving knife edge from an overhead piping system swinging radially on a track from the middle line of tank. The hot knife edge melts a kerf in the ice by its own weight, the cutter blade following in the slot to the bottom of the tank. Both sides of a channel are cut simultaneously, the cutter's blade hoisted by a chain and hand crank, and the frame then shifted forward for another cut. Two cuts of this cutter are made per ton of ice harvested. The ice cakes are quickly hoisted from the tank by a pneumatic hoist on an overhead track, weighed in the air, and run on track to the elevator in north end of building, and lowered to the ice storage cellar or to the shipping room. Ice is cut up as desired in the shipping room, and supplied by a gravity incline to small push carts, in which it is distributed to the cars in train shed, to the restaurant, and to a few water-coolers. Shrinkage of ice in the storage cellar is avoided by overhead direct ammonia expansion refrigerating coils. Accompanying cut shows the method of harvesting by a hand hoist in an ordinary "block" ice plant.

The exceptional purity of the ice obtained at the terminal by this freezing process warrants some mention. In three respects was this noted, viz.:

(1) The almost complete exclusion of bacteria by freezing; the average reduction being over 99 per cent. with the temporarily impure water used in the first six weeks' freezing.

(2) The small number of bacteria found in the tank water after cleansing and refilling tank and using same for four weeks; thus evidencing the fact that the low temperatures prevailing dis-

FIG. 201.—HARVESTING PLATE ICE IN A TYPICAL BLOCK ICE MAKING PLANT.

couraged bacterial growth. Analysis showed 1,790 bacteria per cubic centimeter of this tank water when the city water supplied to tank contained over 20,000 bacteria per cubic centimeter. The plate ice frozen from the same water averaged about 100 bacteria per cubic centimeter.

(3) The great reduction in the amount of other suspended and dissolved matter. The total residue obtained by evaporating to dryness showed that under the worst conditions the ice contained only $\frac{1}{17}$ as much matter as the tank water from which it was made, and that even with the impure tank water used in the first six weeks' freezing, the resulting ice contained only $\frac{1}{6}$ of the impurities found in normal Boston drinking water taken from mains on the same date. In general, the ice was found to be almost as pure as commercially distilled water, and quite as pure as an average sample of can ice made from distilled water. Such impurities as are found in the plate ice are inert and inoffensive, while the can ice core is frequently highly offensive, on account of the presence of lubricating oil from the exhaust steam used, mixed with zinc and iron carbonates dissolved from pipes and tanks.

All the ammonia piping throughout the plant was made of extra heavy pipe with extra heavy steel fittings. Oil traps, ammonia liquid receiver, pipe covering, pressure and recording gauges, ice harvesting and other tools, equipment and accessories are of the usual styles furnished for such work.

The liquid anhydrous ammonia is piped direct to the far centres of distribution in the head house, expanded and evaporated to dry superheated gas in submerged coils in a refrigerating brine tank and similar fresh-water cooling tanks, and is returned at normal temperature, in an uncovered suction pipe, to the compressors. Insulation on a suction line of this length would not save enough to pay for its interest and repairs, for the losses are limited to an increased compressor displacement sufficient to cover the increased volume of the returning dry gas in expanding from zero to 70 degrees. Where liquid ammonia or supersaturated gas is drawn through the suction lines, as in the ice plant, it is of course essential to cover them.

The brine circulating system is used almost exclusively for cold-storage work. A large rectangular steel tank, thoroughly insulated, was placed in the cellar and filled with a strong salt brine solution. This brine is cooled with a number of submerged ammonia coils, handled by either ammonia compressor, and is then circulated by

FIG. 202.—TOP OF ICE TANK—HARVESTING ICE.

FIG. 208.—INTERIOR VIEW OF ICE STORAGE ROOM UNDER FREEZING TANK. STORAGE CAPACITY, 800 TONS.

FIG. 204.—VIEW IN SUMMER STREET BASEMENT OF HEAD HOUSE, SHOWING ONE OF THE WATER-COOLING TANKS AND CIRCULATING PUMP AT LEFT, BRINE TANK AND CIRCULATING PUMP FOR REFRIGERATION IN CENTRE, AND ONE OF THE THREE HOT WATER STORAGE HEATERS WITH THERMOSTAT VALVE AT RIGHT. FILTER FOR WATER-COOLING SYSTEM IS BEYOND END OF BRINE TANK AND CANNOT BE SEEN.

a steam pump through well insulated pipe lines to and through galvanized cooling pipe coils in each refrigerator and back to the tank. The brine is carried at about 10 degrees Fahr., and box temperatures of 20 degrees and upwards are obtained at will by regulating a supply valve on each box coil. For small work of this character, better results in the way of constant temperatures and easy regulation are obtained by brine circulation than by direct expansion in the boxes. The cold rooms and boxes are located on the basement, first floor, and second floor levels.

The water-cooling plant is similar to that provided for refrigerating work in many respects. It was desired to supply with cold drinking water at least 25 taps scattered throughout the building. This was accomplished by using two cypress water tanks, one at

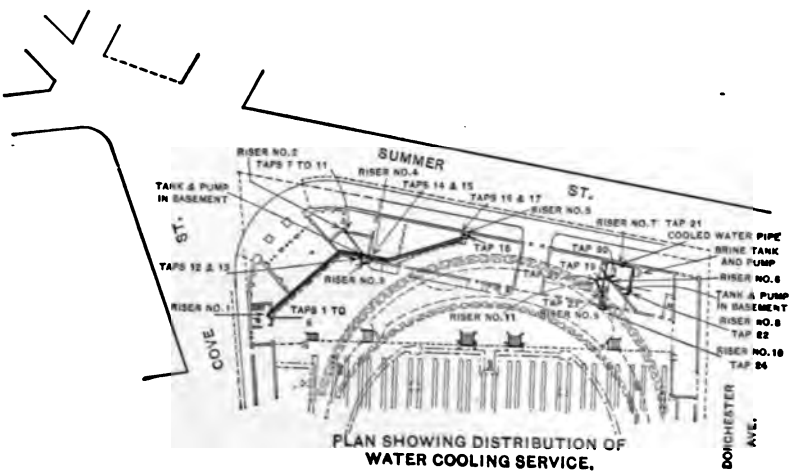


FIG. 205.

each centre of distribution, supplied automatically with filtered city water, which was cooled by submerged galvanized welded ammonia coils connected with the mains leading from the power-house compressors.

A pump at each tank circulates the chilled water through a number of loop pipe circuits and back to the tank. Dead ends at the taps are avoided, thus enabling cold water to be drawn promptly without waste. A constant back pressure is maintained on all taps by a regulating valve, and the rate of flow is from all taps the same regardless of level. This uniformity is secured by use of a special diaphragm fitting with a hole of the proper size to

pass the desired amount of water under the pressure existing at tap. The proper size of these holes was determined by a series of tests under different pressures.

The advantages of this method of cooling drinking water are much the same as cited for refrigerating work. The storage tanks act as flywheels to equalize the loads, and a constant temperature of about 40 degrees is furnished at the taps, this being regarded as the most desirable temperature. This service is a great improvement on water-coolers.

Car Heating in Train Shed and Yards.

This system is designed to simultaneously heat 150 cars in extreme cold weather, thereby keeping trains ready for passengers independent of steam from locomotives. All this work is done by live steam from boilers. Suitable pressure reducing valves are placed at the far ends of the steam supply lines before they branch for distribution to the stub tracks in yards and train shed. This permits the use of small steam supply lines to the centres of distribution, by allowing portion of the pressure to be reduced by friction in the mains. Two pressure reducing valves are used, placed one in head house under the carriage concourse, and one in the transverse subway. These valves deliver a pressure at cars varying from 50 to 70 pounds, according to the season's requirements. The use of hose is avoided entirely; the car connection being quickly coupled to the wrought-iron pipe line by the usual train coupling. The necessary flexibility is secured by a new form of self-packing universal coupling. The lines are dripped by steam traps, and precautions have been taken to avoid trouble from expansion or from freezing. One steam and one compressed-air connection are provided at the end of each stub track. In all respects the system is in accordance with the best practice of other leading terminals, but embodies some improvements.

Air-brake Charging.

This system of piping was designed to serve the ends of 28 stub tracks in the train shed, and a number of additional tracks and sidings in the yards. The outlets are located near the steam outlets of the car-heating system. By means of a generous supply of air, stored in a number of large steel tanks connected with

the compressed-air piping system, the air-brake car reservoirs are quickly charged before the locomotive is attached, and provision is made for testing the application and release of the brakes with a special 3-way cock if required, although it is intended that this testing should ordinarily be done from the locomotive as usual. The compressed air for this work is supplied by an independent plant, having no connection with the air supply for switch and signal work. This plant consists of two standard 9½-inch Westinghouse locomotive air-brake pumps mounted on the wall of the engine room in the ice and refrigerating building, and equipped with automatic governors for controlling the air pressure in the system. One governor is regulated to open at a lower pressure than the other, and starts up its pump when the draught is heavy enough to reduce the pressure below the point at which the regulator of the other pump is set. An air pressure of from 70 to 80 pounds is commonly carried. The air reservoirs and low points of pipe lines are dripped to prevent accumulation of moisture and consequent trouble from freezing. The 3-way cocks at outlets in train shed are each furnished with 10 feet of air-brake hose, with coupling for quickly attaching to the train pipe system, and at the outlets in yards metallic connections similar to those used for steam heat are provided.

Steam and Hot Water Supply to Head-house.

A supply of live steam is furnished for cooking and warming purposes in the head-house, restaurant, kitchen, and serving rooms. An additional supply is provided for heating water in certain closed water-storage heaters for furnishing hot water to outlets in the lavatories, kitchen, bath rooms, porters' rooms, and other points throughout the head-house. Steam is taken from the general main supplying head-house and car-heating outlets, and a portion of the supply is reduced by a regulating valve to the point desired by the kitchen employees.

The hot-water storage heaters are made of wrought iron, with removable cast-iron heads. Heavy copper steam coils are placed in the heaters, and are supplied with live steam at boiler pressure, the condensation being dripped by traps. An adjustable automatic thermostat is attached at each heater to maintain a constant water temperature.

Three of these heaters are used, and are located in their respective centres of distribution. Well-covered hot-water mains are

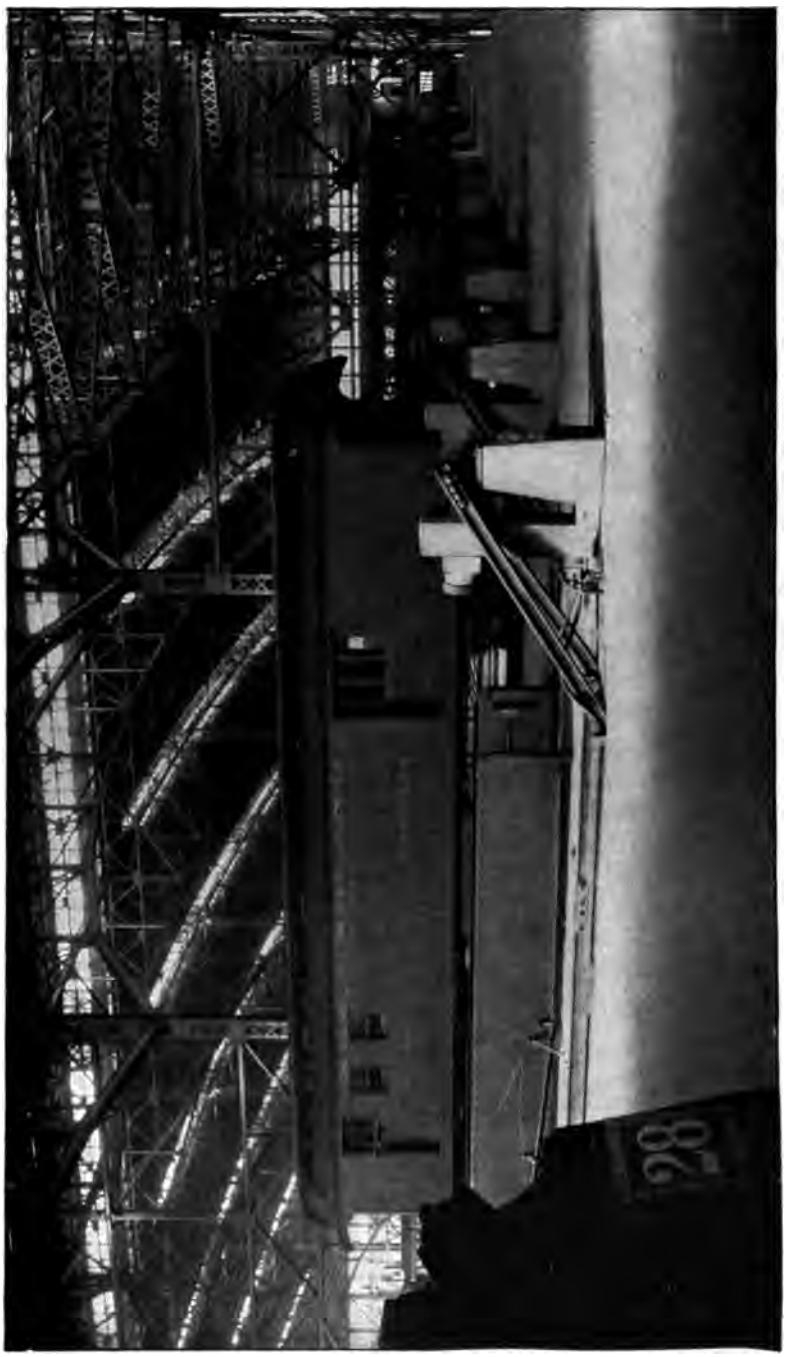


FIG. 206.—INTERIOR OF TRAIN SHED AT ENDS OF STUB TRACKS, SHOWING STEAM AND AIR CONNECTIONS AT BUMPERS. ONE OF THE ELECTRIC BAGGAGE LIFT ENCLOSURES IS SHOWN IN FOREGROUND.

run from each tank to supply smaller pipes which run to the outlets. These are also looped back to the heaters by return-pipe mains, so that a gravity circulation of the hot water is maintained in all pipe lines as close as practicable to the outlets. Accompanying illustration (see Fig. 204) shows one of these hot-water storage heaters.

Fire Protection.

The expenditure which would be warranted to give a good degree of protection against loss by fire was very largely a matter of judgment; determined, also, to some extent, by the methods commonly used in Boston to effect similar results.

The general methods considered were:

(1) Hydrants in yards and outlets in buildings, with necessary hose runs supplied from city pressure, roof tanks, or fire pumps.

(2) Automatic sprinkler service, with or without sprinkler electric alarms.

(3) Automatic electric thermostat alarms, with annunciators in buildings and fire department.

(4) Watchman's service, with recording clocks.

(5) Private fire alarm companies, alone or in conjunction with other methods.

After much consideration, it was determined to install system (1) only at present, supplementing it with watchmen making frequent rounds. Adequate provision was made for the subsequent addition of any of the other systems so far as it should be deemed desirable so to do after experience in the actual use of the station, and after more complete knowledge of the provisions likely to be made by the city of Boston for the protection of the territory occupied. An exceedingly good high pressure city water supply system existing in the adjacent streets, with a pressure maintained at 90 pounds by direct pumping, rendered the installation of fire pumps on the terminal property unnecessary and seemed the surest and best means of obtaining the requisite supply and pressure.

As the water department regulations limit the size of a service from the high-pressure mains to a pipe 4 inches diameter, it was concluded to run a sufficient number of such pipes into the terminal property to supply the necessary number of hose outlets. Each 4-inch service pipe supplies a number of such outlets from a separate horizontal header run in the basements.

FIG. 207.—AIR-BRAKE PUMP OUTFIT FOR SUPPLYING COMPRESSED AIR FOR CHARGING TRAIN BRAKES WHEN LOCOMOTIVE IS DETACHED. LARGE AMMONIA COMPRESSOR CYLINDER OF ICE PLANT AT RIGHT. AMMONIA GAUGE BOARD AT LEFT OF VIEW.

From these basement headers 3-inch risers were run up through the buildings to the roof, with outlets in the hallways of each floor, in the attic, and on the roof. These risers were spaced about 100 feet apart, and a length of 2½-inch fire hose, folded on a rack, was permanently attached to a hose valve at each floor. The roof outlets were protected from rupture by freezing by the use of dripped shut-off valves located in the attics, but handled from above the roof. The means installed seem well adapted to meet all probable needs of the terminal for service of its own.

An unexpected test of the system was given shortly after its completion by the early morning fire which has already been mentioned. A forge left burning over night on the roof by some contractor's men became upset, and the live coals burned through the roof covering into the attic. The resulting flames were discovered by an attendant of the ventilating system, who promptly used the hose to extinguish the fire before reporting the trouble, which would, if not so stopped, have proved serious. This was done with good judgment and but little damage by water.

Since the completion of this work, one of the auxiliary provisions contemplated in the original plan has been installed by The Boston Terminal Company. This comprises several fire alarm boxes, connected with the city fire alarm system, which can be rung from 22 push buttons located in various places.

Elevators, Baggage and Express Lifts.

The determination of the type of elevators, and provision for power for their operation, involved conditions not met in other terminals. Elsewhere, the conditions have been suitable for the usual type of hydraulic passenger and freight elevators and the ordinary hydraulic plunger baggage lift. Moreover, at the time existing terminals were built, no other good method than the hydraulic was available, and inspection of terminal elevator practice therefore aided but little in the solution of the problem.

The ordinary form of baggage lift used at the railroad terminals is well represented by those in use at the Pennsylvania Railroad terminal at Jersey City, where a platform 22 feet by 9 feet, and weighing approximately two tons, is handled by a 12-inch plunger working under about 225 pounds per square inch. Platforms are stiffly guided at points 4 feet 6 inches above and below floor, thereby giving a spread of 9 feet to resist strain on plunger, but requiring protective railing above, and about 5 feet of pit

below floor levels, exclusive of provisions which have to be made for other parts of the apparatus.

Wherever baggage lifts have been used previously, three to five have been usually sufficient, and they have been located within small distances of each other. They have not been exposed to freezing weather, and if located near tide water the conditions have been such that failure of joints involved no more penalty than the inconvenience of flooding the elevator pit.

At the South Station, in Boston, conditions were far more complicated, and in some respects difficult of fulfilment with then standard apparatus. The elevator installation comprises the following:

3	five-story	passenger elevators (in one battery)	speed 250 feet.
1	six-story	" elevator (alone)	" 250 "
1	two-story	" " "	" 250 "
1	one-story	freight " "	" 100 "
1	"	" " "	" 100 "
15	"	baggage and express lifts	" 75 "
2	two-story	" " " "	" 75 "

Of these 24 elevators, the first 7 might have been handled by any method, so far as surrounding conditions and restrictions were concerned; but the baggage lifts were subject to special limitations as follows:

1st. Prohibitions against piercing waterproofed construction, as would be necessary if the usual form of hydraulic plunger lift was used. This restriction applied more especially to 3 of the lifts.

2d. No projecting structure was allowable more than about 3 feet above the level of the train-shed floor.

3d. At least 8 of the 17 lifts were located in situations subject to freezing temperatures.

4th. These lifts were located at great distances from each other and from source of power, being scattered over an area covering many acres.

For the operation of the elevator installation four methods were considered:

1st. Hydraulic (pressures not exceeding 200 pounds).

2d. High-pressure hydraulic (with pressure 600 pounds or above).

3d. Hydro-pneumatic.

4th. Electric.

The first named involved plunger lifts, piercing waterproofing; required pumps, accumulators, and an oil or glycerine and

FIG. 208.—MAIN STAIRWAY HALL. THREE MAIN PASSENGER ELEVATORS IN BACKGROUND; FIRE HOSE AT RIGHT.

water distributing system with necessary returns, covering a large area. Plungers would be exposed to corrosion from tide water, and would require protection by outer casings. With the single plunger, substantial guiding structures projecting above train-shed floor would be required, and with two plungers undesirable automatic devices would be needed to equalize movement of plungers. This system was most expensive to install, and its first cost practically prohibited its use.

The second method had all the features of the low-pressure system, except that it was feasible to avoid piercing waterproofing by using horizontal plungers placed in pans sunk in concrete floor. It involved, however, very high-pressure pumps and pipe lines, a large steam accumulator in power house, a weighted accumulator requiring much height located in head-house; a smaller one in express building, and the usual auxiliary pump required in connection therewith. Its use required the introduction of a new class of service in the system, and although largely reduced from low-pressure system, the cost was still unduly high.

The third method, namely hydro-pneumatic, was regarded as merely a modification of the hydraulic, compressed air being substituted for the purpose of distributing power; the air displacing oil in pressure tanks to operate the elevators hydraulically with the same limitations and objections as for the low-pressure hydraulic service. This system was also very high in first cost, and its use was never seriously considered.

The fourth, or electric method, was practically free from all limiting conditions. It could be supplied with power from an existing system of distribution, which power could be economically generated and distributed. It simplified power house, reduced pipe systems with attendant leakage, and introduced no different class of inspection other than that already provided for the electric motors, electric lighting, etc. Under the conditions met at the terminal, it was the most efficient in operation, and required no relay other than was necessary to provide for other electric service. Under the circumstances, the advantages were largely in favor of an installation of electric elevators, both on account of the superior way in which they met the unusual conditions, and because also of the considerable saving in cost possible with their use. For the difference in first cost between electric and hydraulic systems at this terminal, all the electric operating and controlling devices could be entirely replaced about every six years during

the life of the terminal, and thereby make it pecuniarily possible to take advantage of improvements in such apparatus to such an extent as might be desirable.

The decision to use electric elevators and lifts was therefore made final, and a peculiarly simple and efficient design was made for the baggage lifts to meet the most limiting conditions encountered in several of the lifts operating between the platform level of the main train shed and the passenger platforms at lower suburban loop level. This was accomplished by doubling the gear of a standard freight pattern in a manner permitted by the 3-foot thickness of the iron train-shed floor at the points in question, and within which the controlling and operating mechanism could be placed. This design involved two desirable features; namely, accessibility from above, and avoiding running chains or ropes on a bight.

The platforms were suspended at corners by chains, connected with winding drums driven by longitudinal shafts at either side of the platform, the chain arrangement and design of lifts being shown on the accompanying illustration.

The design of apparatus for passenger and freight elevators was of the standard type made by the Sprague Elevator Co. Elevators are located as shown on general plan (Fig. 156) accompanying this paper. The passenger elevators were designed for carrying a live load of 2,500 pounds at full speed and 4,000 pounds at a reduced speed; freight elevators, 2,000 pounds, and the baggage and express lifts, 3,000 pounds each. The platforms of the baggage and express lifts were each made 6 feet wide and 15 feet long.

One of the most difficult problems to solve in a safe, simple, and rugged manner under the limitations imposed by traffic requirements was the provision for suitable protection around openings for baggage and express lifts. The following features were regarded as essential:

1st. That all gates or other protection must be so arranged that lifts could not be started until the gates were closed.

2d. That elevators and gates be operated from either above or below.

3d. That all elevators in train shed (excepting one) should have means for simultaneously closing and opening gates at both ends of the lift platform.

4th. That such gates should be automatically latched by

movement of elevator platform, and so interlocked that it would be impossible to open gates except with elevator platform at top or so near the top that no harm could come from such opening or to start lifts at any position unless gates were closed and locked.

5th. That suitable bar or other protection be provided in lower level in each case in such a manner that it would be automatically removed when lift platforms were at lower level.

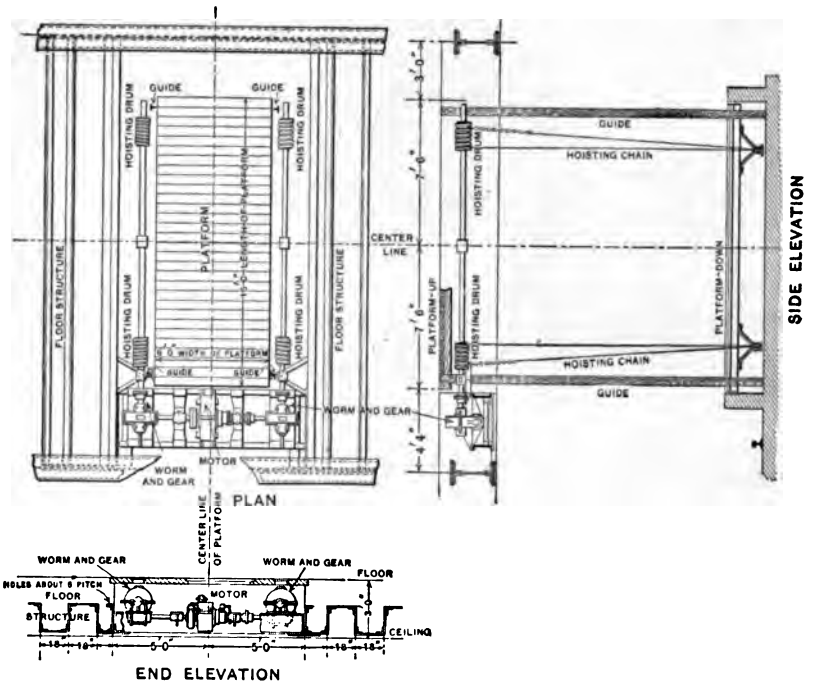


FIG. 209.—SPECIAL ELECTRIC BAGGAGE LIFT.

6th. That all lifts and gates in train shed could be operated from either end of the platform.

This problem was largely worked out by the resident engineer of The Boston Terminal Company, who designed a very rugged and substantial sheet-iron frame about 3½ feet high at either side of each lift opening, and provided at either end of the opening and between frames an iron swinging gate, all being adapted to the various mechanical and electric interlocking devices. This framework cannot readily be wrecked by a heavy truck, and the

FIG. 210.—THREE MAIN PASSENGER ELEVATOR MACHINES AND CONTROLS, LOCATED IN BASEMENT UNDER MAIN STAIRCASE HALL.

gates swing entirely clear and out of the way when open. The gates are arranged so that they both open and close together, and are so interlocked by contact latches that lifts cannot be operated until gates are closed and locked. This arrangement is also such that the gates cannot be opened if the platform is more than a few inches below the upper platform level.

The lifts are operated by foot pushes, a set being located at either end of the platform. The lifts are all supplied with call bells and automatic gates at the lower levels. This type of apparatus is used for 15 of the 17 elevators; the other two, being for two-story service, were provided with ordinary form of drum freight machine, overhead sheaves, and safety devices.

To facilitate the handling of baggage and express matter, a system of subways, connecting with baggage room and express building basements, has been built, and several of the baggage lifts connect these with the train-shed level. These subways are shown on general plan (Fig. 156), and accompanying illustration shows the principal one in perspective. This arrangement not only facilitates the handling of baggage and express matter, but greatly reduces the baggage nuisance on train-shed platforms by diverting a large portion of the trucking to the subways.

Current for the operation of the elevator motors is derived from same bus bars, supplying current to all other electric service throughout the premises, through a loop feeder of uniform size carried through main and transverse subways and building basements.

Except to an unimportant degree, the elevators are located on or near the line of the loop circuit, and the conditions of operation are such that the loop feature in feeder system has made possible an important averaging in the amount of current required for elevator operation and substantial savings in feeder capacity necessary to provide. The entire elevator installation has been in operation for some time under severe conditions, and has been entirely satisfactory in every respect.

The baggage and express lifts were designed to carry a live load of 3,000 pounds at 75 feet per minute through an average rise of 16 feet, the lifts being operated intermittently, some much more so than others. When completed, it was thought advisable to test one of them, to destruction if necessary, to bring out any possible points of weakness. One was therefore loaded with its full 3,000 pounds live load, and an electric starting and stopping

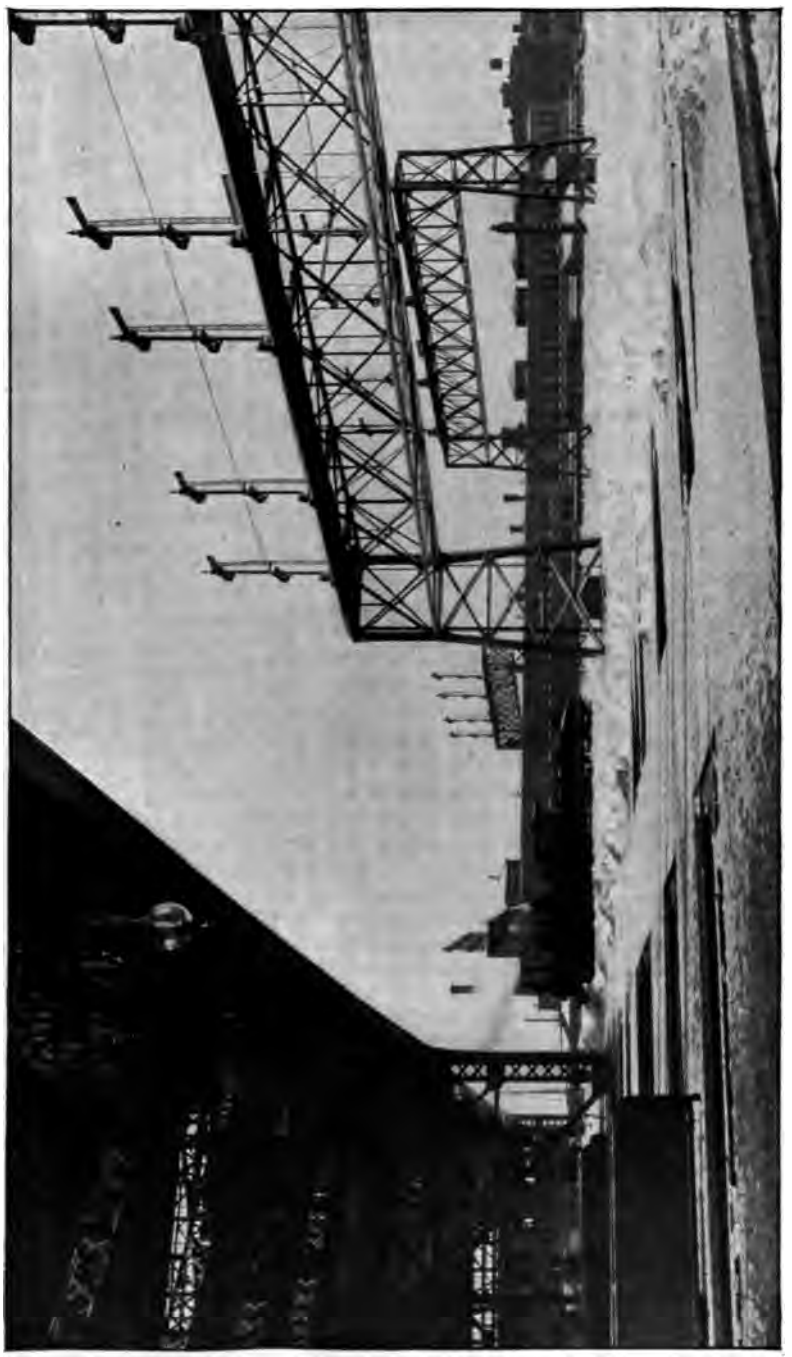


FIG. 211.—SOUTHERN END OF TRAIN SHED IN WINTER. BAGGAGE LIFT ENCLOSURE AT LEFT. THERE ARE FIVE OF THESE LOCATED AT THIS END OF SHED, CONNECTING WITH BAGGAGE SUBWAY, AND ALL ARE EXPOSED TO RAINSTORM, SLEET, SNOW, AND FREEZING TEMPERATURES. (SEE ALSO FIG. 156.)

FIG. 212.—ONE OF THE SEVENTEEN ELECTRIC BAGGAGE AND EXPRESS LIFTS, SHOWING IRON TROUGH FLOOR CONSTRUCTION, WITHIN THICKNESS OF WHICH OPERATING MECHANISM WAS PLACED AND WATERPROOF FLOOR BELOW. DISTRIBUTING CENTRE NO. 7, BEFORE INSTALLATION OF CABINET, IS SHOWN AT RIGHT OF VIEW.

FIG. 213.—BAGGAGE SUBWAY UNDER TRAIN-SHED TRACKS. THERE ARE FIVE ELECTRIC BAGGAGE LIFTS LOCATED AT THE FIVE RECESSES IN THE RIGHT-HAND WALL.

device was so set as to automatically trip at each end of the lift, and the platform allowed to thus run at full speed with full load for 10 hours. Careful inspection during and after the test showed the entire apparatus to be in perfectly normal condition, no weakness being developed.

DISCUSSION.

Mr. George I. Rockwood.—To deliver any eulogy of the Southern Terminal at Boston would be something like patting the Forth Bridge on the back. It is too big for any man to attempt to applaud it in the ordinary way. Every engineer who lives in the vicinity of Boston has, of course, seen the station, and on one occasion I was shown about this engineering plant by one of the sub-contractors. I did not wish especially, in rising to speak on this paper, to refer to the mechanical details of the plant, for I think that, perhaps, to us as a society the most important single feature in the paper is that which deals with the novel fact that the contract was let to a firm of engineering contractors who were also the engineers of the plant, although there were Mr. Leavitt and his board of engineers over all, and theoretically we have a consulting engineer and a firm of contractors, as is customary. But, as I understand it, practically the fact was that Westinghouse, Church, Kerr & Co. actually assumed the design of, as well as the contract for, all the details and improvements in the general arrangement. The question arises therefore whether the position occupied by this company is, in engineering work in general, one which is to be commended as a proper course to pursue, or an expedient policy to be followed in the future; and whether the engineer as such is going to join a corporation sooner or later and work in its interest, or whether an engineer as such is in the future to have complete responsible charge. I believe it is customary in New England for engineers to simply specify the goods that are to be bought, but not to buy the goods themselves. In my own case that is not so. I have had but one installation where I have not bought everything that was bought. I have been made an officer of the company; that is to say, I have been given a power of attorney from every corporation with which I have ever done considerable business, with this one exception, and that is possibly also a unique position to occupy, for it was not premeditated on the part of these people who employed me; it was my own desire. I have found that an engineer who occupies

that relation to a company—the relation of a purchasing agent—occupies a very advantageous position in behalf of the company. He also occupies a position of great temptation and great responsibility. Nevertheless it can be said that the contracting engineer, who also is the designing engineer, is tempted twice to pervert his powers where the purchasing agent is tempted once. The purchasing agent gets his commission from the corporation which he serves, and is supposed to take no commission from any other living soul who deals with him. He is therefore in a position to effect the best trade, because he knows the technical merits of the different articles offered, and he is also known to be the responsible buyer. But the contractor who also is the engineer has, of course, to make a percentage on the goods, and then, after receiving the contract and being his own inspector, may design the goods to enlarge the percentage. We come back to the morality of the contracting party after all, and I am not prepared to say that I believe it is unwise to employ a contracting firm of engineers as the designing engineers. I think it comes back to the question of man and man, just as all such questions finally do; but the very worst possible policy which can be followed, in my opinion, by any corporation is to suspect either its engineer, or, provided the contractor is also the designing engineer, its engineering contractor. Such beautiful relations must exist between the contractor and the party of the second part where such a contract is entered into, as described in this paper, as do not perhaps have to exist under other forms of contracting to get the same results. I have heard it said that the great ships of the White Star Line have nearly all of them been bought without any legal instrument passing between the buyers and the sellers. I do not know from my own knowledge whether that is true or not, but I was told that the corporation owning the ships decides to buy the ships, and that then its managing director goes to the firm of Harlan & Wolf and sees to getting the ships built; and they are built. Probably that is the highest relationship that can exist between the contractor and the buyer, but it is altogether too good to be true in ninety-nine out of a hundred cases. I incline for my own part towards the employment of engineers who are utterly disconnected from any firm, and placing absolute reliance upon their judgment, financial and technical.

Mr. William Kent.—The paragraph to which Mr. Rockwood refers I think is the most important in the paper, and I hope that

the whole subject, stated there in outline, will be made the subject of discussion. I would like Mr. Kerr, if possible, either in this discussion, or in a later paper hereafter, to answer this question, if he can put himself in the position of a purchaser, of the man who wants to buy a very large plant with every kind of apparatus, what is the best way for him to get the best thing and not pay an extravagant price for it? There are several different ways of getting plants built. The way I was accustomed to in Pittsburg, where I lived twenty years ago, was that a man who wanted an extensive plant would go to his friend in the neighborhood, who did the thinking for that locality, and say: "What do you think I had better have?" He would write a few letters to the people in town that built that sort of plant, and they would put up boilers and engines and machinery just as they used to do before. The result was that he got a pretty good job as regards strength and durability, but there was no progress. It was not until new blood came in with new ideas that anything was done better than that. I asked a mill owner one day if he was going to put in a Corliss engine or a Porter-Allen engine. He said: "We are going to put in an old-fashioned slide-valve engine. Nothing else for us." They kept on that way. That is one kind of engineering. The other way is the way followed by the Calumet and Hecla mine. They employ Dr. Leavitt to do their engineering, and I understand he designs every detail and has the things all built to order. That is an excellent method for such concerns as the Calumet and Hecla. Then there is another method—the consulting engineer's method, the English method, and that is a very good one. Then there is the day's labor method. I understand a contract is now being executed in this city where the man does it for cost plus 15 per cent. profit, and there are several men engaged in carrying brick from one pile to another and back again, and that is all charged in order that the contractor shall get this 15 per cent. on useless labor. Then there is this new way of Westinghouse, Church, Kerr & Co., which I think is quite unique. I do not quite understand it. I hope Mr. Kerr will give us more particulars of how this is done, why it is done, and why it is best that it should be done.

A friend of mine came to me the other day and said: "I want to get an electric plant, say 50 kilowatts or so; I want a boiler, engine, dynamo, and all that sort of thing; how had I better get it?" I was not particularly caring for the job, and I said: "The

easiest way to do that probably is to find out where you want these lights and how many of them, and go down to Westinghouse, Church, Kerr & Co., and they will do the rest." That was the easiest way out of that particular problem; but whether that is the best way or not I don't know. I will leave Mr. Kerr to tell us.

Dr. Robert H. Thurston.—I think the most important matter we have before us just now is the fact that we have this paper, and I want to congratulate the society very heartily in having secured this particular paper and a paper of this particular sort. I was talking with an old member of the Society yesterday, who said: "We have been getting too many professorial papers," and I agreed with him entirely. We came to this common conclusion: That because men of the other sort had not come forward, we had been reduced to dependence upon the professorial sort of paper.

While congratulating the Society on securing this admirable representative of a certain class of papers I want to congratulate also the gentlemen who prepared the paper, and particularly the firm that they represent, on the splendid way in which that work has been done. In the history of the profession there never has, I think, been a more magnificent opportunity more splendidly taken advantage of than is illustrated in the work of which this paper is a description. I think that fact is the really important thing. I think, further, that the fact that these gentlemen have come forward and given us so complete an account of their work and displayed the whole business end of it so frankly and completely, and have given such an admirable general description of methods of construction, of design, and of operation, will enable us hereafter to reduce the proportion of "professorial" papers, and to secure more generally the sort of paper that we need most. What the "professors" want, also, is this kind of a paper. What they present is the matter that they happen to know something about. What they wish to read is the thing they know less about, but which they are too often expected to know all about. If we can find in the *Transactions* of this Society, every year, a fair proportion of papers of this class, I think that not only the professors, but all other members, will be deeply grateful to the gentlemen who present them; it will be vastly to the advantage of the Society as a whole. I also feel grateful to the gentlemen presenting the paper, because they are setting so good an example to the younger members who are now coming forward and who, more than the

older members, have usually had opportunities of preparing themselves to tell what they have done, as well as of doing things in modern ways, and we now look to the junior members of this Society to study these papers with care and, later, to show us how our papers can be improved upon, even if they cannot show us how the work is to be improved.

A Member.—Referring to the saving of about $100,000 on three-quarters of a million on this contract, it is to be expected there would be saving from the method of designing. Apparently this work was contracted for at somewhere near the bottom of the market on metals. I would like to ask Mr. Kerr if any portion of the saving of $100,000 on three-quarters of a million might not be due to the price of material at the time the contracts were made.

Mr. Kerr.—It really had nothing to do with it. The $100,000 mentioned is an estimate made by comparing what other terminals paid for certain things and the cost of similar things here, equated as nearly as could be by allowing for the difference in size and amounts of apparatus installed. In addition to this there was a further saving due to prices of material. The difference was chiefly represented by what could have been saved in the other terminals if their work had been correlated instead of divided into separate jobs with no relation between them. I could tell you of a terminal where a power plant was installed with its boilers for 125 pounds; meanwhile the heating of the head-house was so planned that it could not be done on exhaust pressure, nor on boiler pressure, and they put in another set of boilers. That terminal to-day has a double set of boilers.

The Member.—I am glad to hear this reply, for this reason, that this saving of $100,000 is due to the use of engineering brains. I am glad to hear it.

Mr. John Platt.—The whole tendency seems to be to discuss the question of the saving made by the method employed in contracting for and carrying out the work on this building. We were just told that it is the question of the engineering brains that brings it about. Now the whole thing has been discussed a good deal at the present time in a series of articles in London *Engineering*, in connection with the question of American competition. The consulting engineer is referred to also, and his connection with the work; that it is a very important one is shown by the methods of carrying out work in England, particularly when comparing them with the methods in this country, and the

action taken generally by the consulting engineer, particularly in London, in relation to contractors. There the whole tendency seems to be, as much as possible, to make everything and design everything as different as a man can from the ordinary standards, and to cause the contractor as much trouble as possible. This is putting the worst part of it forward; but there is a great deal of it done. I know a great many offices in London where this method is carried out. Then here the consulting engineer places himself much more closely in touch with a manufacturing establishment, and designs the work so that they can carry it out economically. If people want a particular plant, and they simply go to the contractor and say, "We want so and so, and you design it and give us the price for building a good plant," no inspection being called for at all, and the contractor being allowed to make just what he sees fit, and when he can do this, of course, the cost is cut down to a minimum. I was very glad to hear one thing; viz., that Mr. Kent should ask for a paper which should put before the Society the whole subject as between the two methods —the extreme English method and the method adopted somewhat in this country—and to point out which is the better one for us to adopt.

Mr. Reginald P. Bolton.—Mr. Kent could himself write such a paper with considerable force, because he occupies the position of a consulting and independent engineer, and it is only from that standpoint that this question can be properly treated.

One point that was mentioned by Mr. Kerr in connection with his last remarks I think bears very greatly on the whole subject. He said that the architect did this and the architect did the other. Those are the people who make all the trouble. They stand between the consulting engineer and his living, and they get the contracting engineer to do the work for them. The architect who laid out that faulty system referred to was paid two and a half, possibly five, per cent. for doing the work he did so badly. If he was paid for doing the whole work, then Mr. Kerr's firm carried out the work for him in the first-rate manner described, and saved him that amount of money. That sort of thing is going on in this city every day in the year. The architects in this city are 550 in number, and out of that lot there are not more than twenty who employ engineers and pay them. Out of the rest another twenty have their own engineering draftsman in their office, whom they employ to lay out, as they say, engineer-

ing work—a class of man of limited experience. The other 510 uniformly get their whole engineering work done for them by contractors for nothing. That is a standing scandal, to my mind, and it has grown out of the gradual growth of much of the architectural work into engineering work, which has now gone beyond the stage where an architect can properly deal with it. That is known to all gentlemen who are engaged in manufacturing business, who have to go to great expense to prepare plans for this class of professional men, who send them sketches of a building and expect a steel structure to be designed, or send them a ragged sketch of a building and expect it to be heated for them, and the question has cropped up from time to time, but has never been seriously dealt with. The architectural societies must be well aware that this is the state of affairs, and it seems to me it is time that the engineering societies took the question up, and insisted that the engineering element in this country have its share of what is paid out for engineering work, because a double loss is occurring. Not only is the engineering profession not receiving what it ought to have, but it is actually having to do work for nothing, for which the architects are putting the money in their pockets. This work is not merely in relation to small buildings, dwellings, etc., but it has got up to the stage where architects undertake to tackle power stations, so that it becomes a very pertinent matter for the engineering societies to deal with.

With reference to the question of a contractor being allowed to draw specifications, there is another method which I see very much employed, especially in public work, and which is a very poor one, and that is, while employing engineers, to instruct those engineers to prepare specifications, which I call fishing specifications, which are simply sent out to cover any class of machinery which will by any hook or crook fit into the circumstances that are required. That practice is very disastrous to the purchaser and very often to the seller, for the reason that under such specifications as that a large number of plans have to be prepared at great cost to the general trade. Out of them probably the lowest bidder or the most favored bidder has his bid accepted. His apparatus is ordered to be installed, and is then installed under the specification, which contains provisions which do not specially relate to his machine, but to any class of machine. For instance, I have been for several years engaged for the city of Brooklyn in endeavoring to see carried out an in-

stallation of an important pumping plant of direct-acting tri-compound engines, under a specification which was manifestly written for a fly-wheel engine of a totally different character. The consequence is that in a large number of detail points, where the circumstances of the plant would require certain apparatus, no provision of the specifications can be made to apply. That sort of thing comes up constantly before consulting engineers.

Mr. Platt's reference to the difference between English practice and American practice is somewhat to the point. English engineers are very fond of designing special machinery. That prerogative is not entirely their own, however. It is done to some extent in this country. It is perfectly practical to draw a specification which will include certain standard machinery; but when it comes to the details of connection and the specialties which are required in those connections, then the engineer's ability and knowledge should come in, and he should define precisely what he wants and he should be able to design those things in detail so that they should not be laid as a burden on the contractor. For when all is said and done, somebody has got to pay for designing and for the brain work in connection with all this work, and if the contractor does it, acting also as consulting engineer, he has somewhere or other to make a profit. It has got to be paid for in the price of his contract. Otherwise he is at a loss, and his standing charges are running up against him.

I have been told that, in connection with steel structural work, some of the large firms maintain, not merely a dozen men, but scores of men—in one case over a hundred men—making designs for the steel structure of buildings, which designs are given away gratis, and for which they charge absolutely nothing. Now, they must in some way get money for doing that, and they add it on to the price of those contracts which they obtain. I think this state of affairs is not a right one, and calls for some action on the part of this Society, and for its influence to get the brain work of designing engineering appliances and engineering plants into the hands of the proper class of men.

*Mr. Kerr.**—I seem to have been called upon to say something in respect to several points. Mr. Kent has asked that a paper on the subject be written at some future time. I have not much use for anything written a year or two hence. It should be either written now or not at all. The subject is interesting. I think

* Author's closure, under the Rules.

many of the remarks made are timely and well taken. A good deal depends on the point of view.

I think the easiest solution of the questions raised is for us to settle them through such tribunal as we may appoint to determine just what kind of food we shall all eat and what kind of clothes we shall all wear, and what we shall all do for amusement. There are different ways of doing things, and different people believe that certain ways are better than others. The good ones eventually succeed and the bad fail. It is easier to discuss different ways than to decide which is the best. The broader the field of operation, the more room for many acceptable ways. If any one has something he thinks is good, the way to find out is to try it. If it succeeds it may be better than others have found, or possibly more meritorious than some one else understands. While more or less is said in the preface to this paper favoring the way in which this work was designed and executed, it is by no means intended to advocate it exclusively. It is simply a successful way which has met existing conditions and continues to meet them in many large enterprises.

In reply to Mr. Rockwood's remark regarding temptation, I think it is better to tempt one man twice than two men once. (Laughter and applause.) Mr. Rockwood has exemplified the fact that under the conditions and limitations of his practice he has found a preferred method. It is to his credit that he advocates the way which he has found good. Others evidently approve it, for they continue to use it, and that is why Mr. Rockwood continues to find it good. In the main, his way involves concentration of responsibility, which suits me. He is quite right in his statement to the effect that honesty must underlie any equitable relationship, and that honesty must reside in the individual man. This reminds me that there is another kind of honesty besides that which does not take money unlawfully. It is the honesty which neither deceives itself nor others, and which takes no risks for others on its own ignorance. It is just as requisite for success as common honesty.

I see no need of quarrelling with the ways of engineers nor of arraigning architects for their methods nor censuring contractors for contributing engineering design to the welfare of their work. It seems proper, however, to try to identify the results obtained, and determine how far they are due to method and how far they represent skill and knowledge independent of method. When

discussing engineering versus contracting, it may be also well to make clear whether we are considering contractors doing engineering or engineers doing contracting.

The tendency which has been referred to of manufacturing concerns making plans and specifications which some think should be made by consulting engineers has at least part of its origin in the fact that these concerns have found by experience that to get work done, done rightly and expeditiously, requires putting into the designs and specifications more constructive talent than is usually furnished by those who do not themselves construct, and the fact that the practice has grown rather than diminished is some indication that it is found good. It seems to have found peculiarly fertile soil in structural steel work. Certain causes have an old-fashioned way of producing certain results, and it may be accepted that there are some reasonable causes behind the willingness on the part of manufacturers to undertake at large expense to do work which, according to conventional customs, ought not to be required of them.

Something has been said of the engineering habit of "special design." I think all habits are likely to be bad. Even good habits may be inadvisable if they preclude the formation of any new ones equally good. The power to vary is an essential feature of life and progress, but efficient variation is a steady increase, progressive and reasonable, and is not to be confused with erraticness nor associated with inconsistency. Objections cannot truly be raised to designs and specifications because they are special, but because they are unreasonably special, and it is the unreasonableness which is objectionable. Who shall be the judge? There are many, but one of them should be the man who has to construct and guarantee the work.

I once heard an animated discussion which ended with the declaration by a contractor to a marine architect that "the yacht could rust on his stocks before he would rivet the centreboard trunk in a way which would send her to the bottom of the sea." His ultimatum won. He was only a boat-builder; but I knew that he was fitted by a foreign university education, by technical training, and constructive experience to be the only "judge" present.

But with reference to the main subject of engineering ethics, and whether the method adopted for creating this plant was in accordance with good custom, I would venture the assertion that

practice must always precede, and, if successful, the immaterial things, like customs, follow in the wake, adapting themselves to the force which pulls them along. I believe that the process of evolution will go on and you cannot make laws that will stop it. I believe that there is room for every man with talent, and you cannot legislate any man into a place where he can exhibit talent which he has not got. The talents of some men are advisory. They can tell people how to do things, and though they could not do these things themselves their advice is good. Others seem to manage to get things done well. They lack initiative, but they know how to push what others have originated. Some are brilliant, but lack the fly-wheel of steady nerve. Some are not good advisers because they lack that gravity and balance which come only from making or losing money themselves and not for their customers.

There are restricted lines in which a man may become highly specialized. Such a man becomes a good adviser and competent to make designs and specifications of the things he knows all about. Others meanwhile develop similar qualities in other directions. Finally, many such men exist, but certain work is broader than any one of them. They need to work together to do a job right. One of them can take the whole job and do part of it well and the rest badly. That is the limitation of being only one man. If each of us could be a lot of men, each would be a lot better; but we are each one man. This encourages organizations of men to do the many things which one man cannot do but that many customers want done, and which need to be done together.

I might say a word about the difference between aggregations of men who advise and combinations of men who construct. I see no reason why wisdom should not flow from an aggregation of wise men. Sometimes it does. That is when they are more than wise. It is when they are all good, able, liberal, generous, practical, of strong personality, but not unduly tenacious, reasonably modest, and withal a hard combination to get. Such men may determine upon the best of many ways, but more often bodies of engineers thus associated in purely professional capacity finally determine upon a series of compromises, perhaps more or less mixed with antiquated methods and apparatus and a few of the most venturesome things upon which the boldest have insisted. I would rather have one good consulting engineer than

several. That one can, if necessary, get advice from others, which he can follow or not on his own judgment.

My experience with aggregations of constructors is different. The attributes enumerated above are desirable, but it is so much harder to compromise things in fact than on paper that there seems to be a peculiar realizing sense borrowed from the constructive faculty, which enables such men to help each other more than is customary in professional work. Even though this be true, the fact still remains that it is desirable and even necessary to have some one man over all, whose voice is final and upon whom the moral and financial responsibility rests heavily. After all it comes back to one man power, where some one must take the complete responsibility for making things right.

The present tendency in engineering seems to be to trust the judgment of the man who can himself do things. While a lot of engineers coöperate thus to actually execute work, some are not trying to perform the work themselves but are advising how it should be done, and honestly guarding their clients' interests, seeing that the work is executed as well as it can be done through contracts let in the ordinary manner; they do not pretend to do things. And I maintain that there is room for all in this great, big, progressive world. There are many, and the number seems increasing, who, when they want work done, care little and know less about details, but they want to know that it will accomplish a certain result and will cost a fixed price. Of those two things they must be absolutely sure. But who is to be responsible for producing that result and guaranteeing the cost? It must be the engineer-contractor. The necessities of others make room for him. No man, however able, no concern, however competent, will ever absorb all the work. Each will secure that which he can do best, and his talents will have full opportunity to earn all the money and all the reputation that they can bring.

Certain anomalies and difficulties exist of which we are all aware, but I will not enter into their details. They largely take care of themselves. Freak things don't win, but anything based on a fair exchange of money for the execution of good work and carrying of responsibility will always win. The work will distribute itself properly in quantity and degree to those who provide themselves with the various facilities for doing it. I think there will be no need for exact lines between one kind of

an engineer and another, no need of an engineering moral and penal code, and no room for those who do too much thinking and not enough acting. I think that the whole question really needs no answer. It resolves itself into room for all with different good ways of doing things. (Applause.)

No. 846.*

A METAL DYNAMOGRAPH.

BY PAUL MELLEN CHAMBERLAIN, CHICAGO, ILL.
(Member of the Society.)

THE machine here described was designed for the purpose of giving a definite test of the machinable qualities of cast-iron specimens, and at the same setting to prepare the specimen for accurate tensile tests. It was built in the shops of the Lewis Institute, and serves as a part of the experimental laboratory equipment.

It consists essentially of a lathe swung as a cradle dynamometer and an autographic apparatus. The lathe is adapted to specimens 18 inches long. The carriage carries two cross slides, one with the testing tool, and the other with forming tools. The power feed gives $\frac{1}{48}$-inch movement per revolution of specimen. The spindle is cast iron, with babbitt bearings $1\frac{3}{4}$ by 2 inches. The end thrust is taken by twenty $\frac{5}{16}$-inch steel balls and tool-steel collars. The cradle bearings are carried on fourteen $\frac{5}{16}$-inch steel balls in tool-steel races. The autographic arrangement consists of a pencil attached to the carriage, and marks on a concave card concentric with the swing of the machine. The general arrangement of the machine is clearly shown in Figs. 214 and 215.

For a test bar suited to the two tests—dynamic and tensile—the form shown in Fig. 216 is used. The same figure shows the form of clamp used in connection with the tensile test to secure an axial pull. The clamps are of hardened tool steel, and are held together by a neat-fitting wrought-iron ring. The shoulders of the straining bar and the specimen are turned spherical, as also are the shoulders of the clamps.

The diagram formed by the pencil shows the pounds pull on, and the distance moved by, the tool. This, with the time of cut, gives the variable factors for the horse-power used. The friction

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

of the machine can be read from the card where the pencil marks before and after the cut. The additional friction when doing work is nearly proportional to the work, presenting no great error, yet one which can be corrected, if so desired.

To secure comparative results, it is necessary to have the tool conditions constant. The subject of rake and clearance angles consistent with the minimum resistance in cutting various metals is a field of investigation in which this machine will be useful.

The tests here recorded were made with a tool having angles

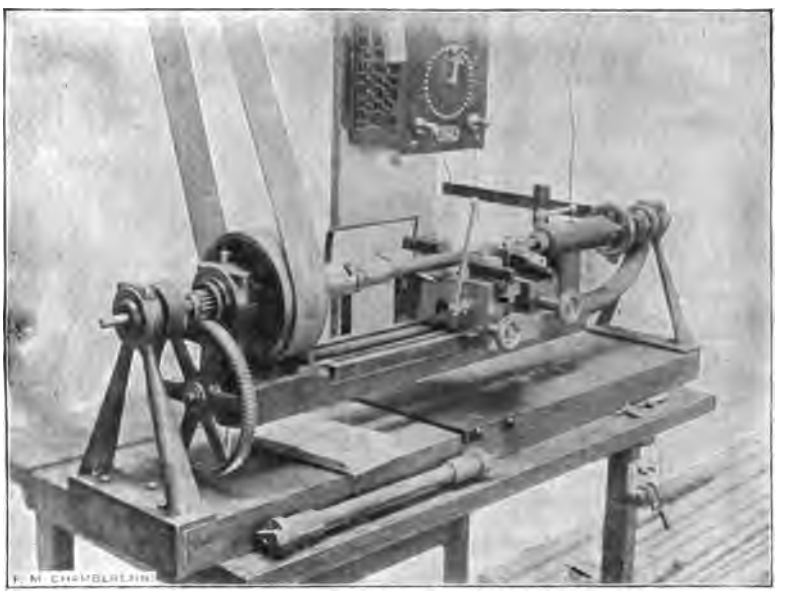


FIG. 214.

as indicated in Fig. 217, the horizontal line from which the front rake, F, is measured, always passing through the axis of the specimen.

The radius of the driving pulley is 3.819 inches, one revolution giving two feet of belt travel. The scale for measuring the cards is proportioned to give the pull in pounds at the radius 3.819 inches. Dividing this by the mean radius of the cut gives the actual pressure on the tool. The feed being constant, the volume of metal removed is proportional to the mean radius of cut, hence the ratio of metal removed to card reading is independent of the radius of cut. This assumes that the mean radius locates the

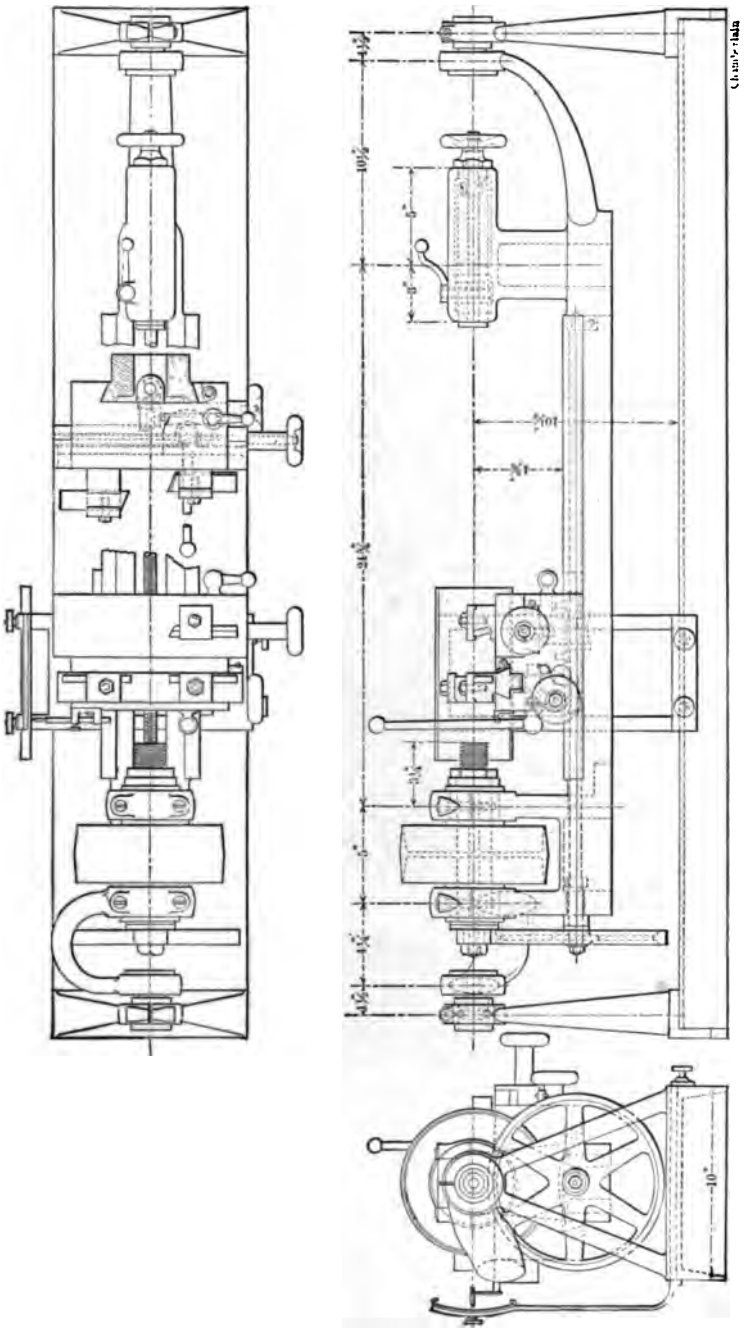


FIG. 215.

centre of pressure on the tool, and that $2\pi \times$ mean radius $\times$ depth of cut $\times$ feed gives volume of metal removed. The error involved is not important.

The edge of the tool is the factor most difficult to maintain constant. It is therefore desirable, before any test, to take first a uniform cut and ascertain how far the tool will cut without getting dull enough to appreciably increase the pressure.

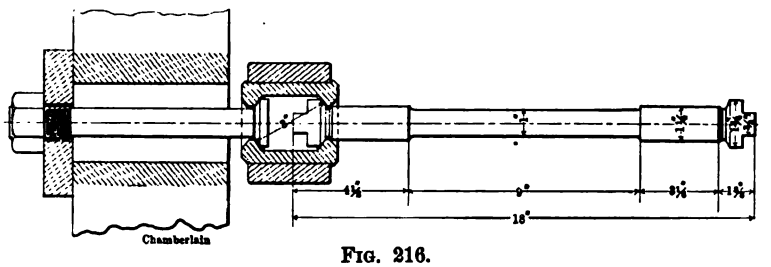


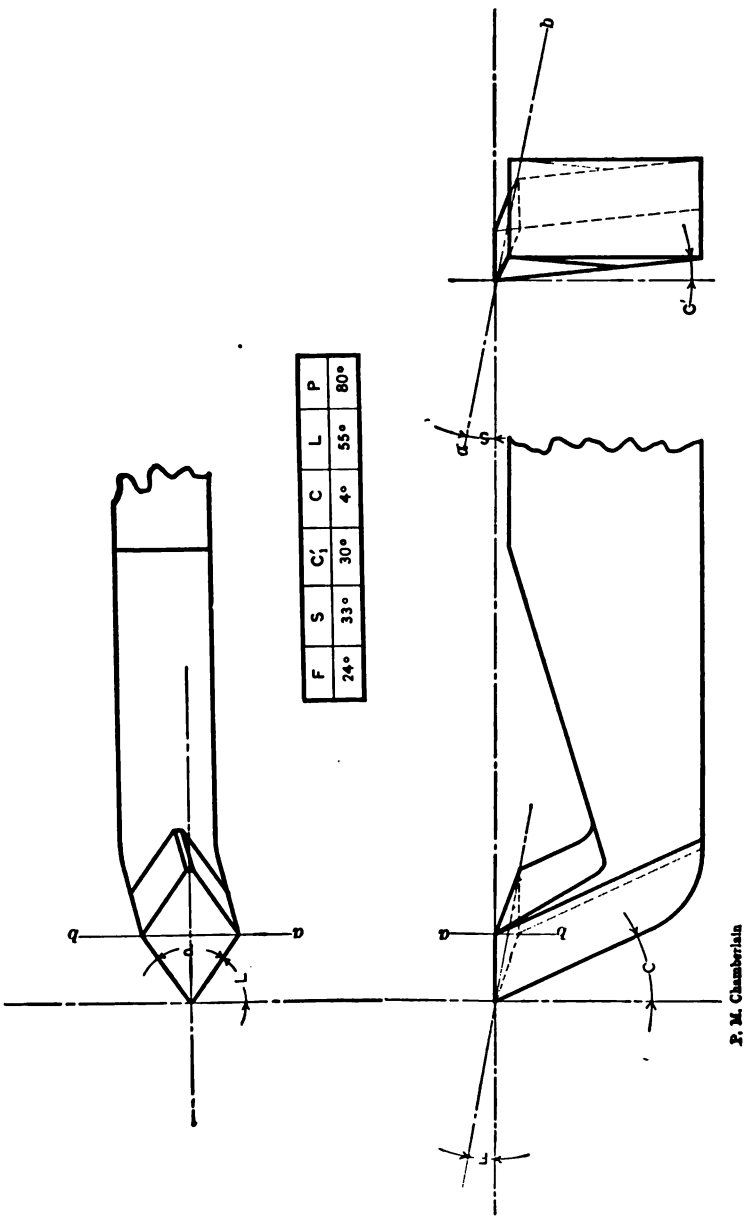
FIG. 216.

In taking a cut of 8 inches with uniform speed and 20 pounds pressure at the card, the dulling of the tool increased the pressure about $\frac{1}{2}$ pound. Duplicating the cut, but gradually increasing the cutting speed from $8\frac{1}{2}$ to $17\frac{1}{2}$ feet per minute, showed no appreciable increase in resistance over that due to the dulling of the tool.

Table I. gives the tests on two pieces of cast iron from different foundries, one being a "pulley" iron and the other a medium hard iron.

TABLE I.

Pounds Pressure at Radius of 3.819".	Original Diameter.	Final Diameter.	Depth of Cut.	Mean Radius.	Sq. Inches, Cross Area of Metal Removed per Revolution.	Cutting Speed in Feet per Minute.	
$7\frac{1}{2}$	1.243	1.214	.015	.614	.057	15.6	Medium hard iron.
11	1.243	1.203	.020	.611	.076	15.6	
15	1.243	1.178	.032	.605	.111	15.6	
18	1.243	1.172	.035	.604	.132	15.6	
23	1.243	1.148	.041	.597	.171	15.6	
28	1.243	1.123	.060	.591	.222	15.6	
34	1.243	1.102	.070	.586	.257	15.6	
14	1.440	1.370	.035	.702	.154	26.3	"Pulley" iron.
20	1.440	1.340	.050	.695	.218	26.3	
30	1.440	1.284	.078	.681	.338	26.3	
$34\frac{1}{2}$	1.440	1.253	.093	.673	.401	26.3	
45	1.440	1.192	.124	.658	.516	26.3	
$41\frac{1}{2}$	1.370	1.142	.114	.628	.453	26.3	
$34\frac{1}{2}$	1 340	1.142	.099	.620	.390	26.3	
$23\frac{1}{2}$	1.284	1.142	.071	.606	.265	26.2	
18	1.253	1.142	.055	.599	.206	26.2	
$8\frac{1}{2}$	1.192	1.142	.025	.583	.091	26.1	



F	S	C'1	C	L	P
24°	33°	30°	4°	55°	80°

FIG. 217.

P. M. Chamberlain

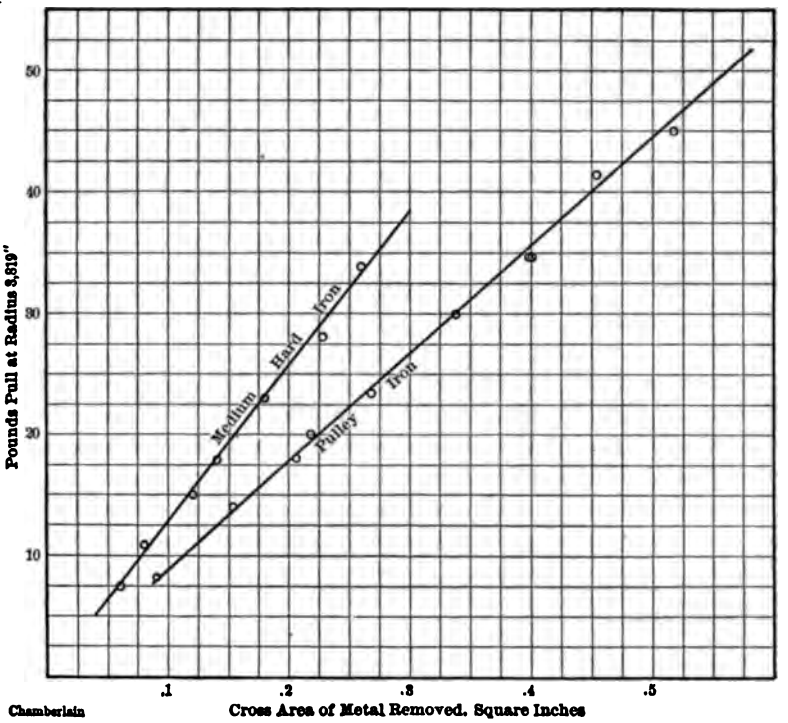


FIG. 218.

FIG. 219.

The pounds pressure as vertical ordinates and the cross area of metal removed as horizontal ordinates are shown plotted in Fig. 218. The plotting of pressures and areas gives a check of the correctness of the results, as any changes in conditions will give an irregular curve. Fig. 219 shows one of the cards from which Table I. was obtained. The vertical lines in the original card were 1 inch apart.

The experiments thus far made show that the pressure on the tool is independent of the cutting speed, and that the metal removed is proportional to the pressure, measured at a constant radius.

The most enduring form of tool and the ratio of cutting force to the rate of volume removed for a given life of tool, would seem to be the necessary data to make such curves as shown on Plate —, definite and comparable tests.

For the accuracy of construction necessary to make the machine described above sensitive enough for accurate results, the writer is indebted to Mr. C. E. De Puy, member of this Society.

DISCUSSION.

Mr. H. H. Suplee.—I simply wish to call attention to the fact that this dynamograph resembles very much one which has been tried in France, I think by MM. Huillier and Frémont, and some very elaborate tables were given of results of a very similar apparatus, which I think would be interesting to compare with this. In that case the dynamograph was attached to the face-plate of a lathe to indicate the resistance and also a spring pressure behind the tool so that the pressure of the tool could be measured.

The original memoir of MM. Huillier and Frémont is entitled "*La Production des Machines-Outils*," and appeared in the *Bulletin de la Société d'Encouragement pour l'Industrie Nationale* for April, 1899, and may be found in the library of the Society. An abstract of the paper is given in the *Engineering Magazine* for July, 1899.

*Mr. P. M. Chamberlain.**—The resemblance of this machine to that used by MM. Huillier and Frémont is not very striking, inasmuch as theirs was an adaptation of the Morin dynamometer

* Author's closure, under the Rules.

depending on the calibration of a spring, and this an adaptation of the Nadee dynamometer, depending on the pendulum weight. Their aim was to determine the power used by machines by using two dynamometers—one between the work and the face-plate, and the other leading to the machine. The aim in designing this machine is set forth in the first paragraph.

No. 847.*

A CURVED GLASS BLUE-PRINT MACHINE.

BY PAUL MELLEN CHAMBERLAIN.

(Member of the Society.)

THE desirable features of a blue-print machine are ease and rapidity of operation, such adjustment as to secure the direct rays of the sun, and means whereby close contact between the tracing and the sensitized paper may be secured. The machine here described and illustrated (Fig. 222) was designed to meet the above requirements, and was first built for, and in the shops of, the Lewis Institute.

The operation of the car and the universal adjustment is so clearly shown in Figs. 220 and 221 that explanation seems unnecessary. The iron work is all galvanized to avoid rusting after exposure to rain or snow. The glass is curved to a radius of thirteen feet. Attached to one end of the frame is a sheet of canvas-rubber packing about one-thirty-second of an inch thick. The other end of the rubber cloth is fastened to a steel tube which serves as a roller to roll the cloth on and also as a stretcher. Square projections at each end of the roller are engaged by hook cams as shown in Fig. 223, which are operated by eccentrics on each end of a steel rod, rotated by a handle at one end, through an angle of 180 degrees.

The operation is this: The rubber cloth is rolled back on the steel tube, and the paper and tracing are placed on the convex side of the glass; the cloth is unrolled with one hand, leaving the other free to adjust or turn down crumpled edges of the tracing, as shown in Fig. 224; the ends of the steel roller are engaged by the cams, and a turn of the handle stretches the cloth, giving a pressure component normal to the glass; the frame is turned

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

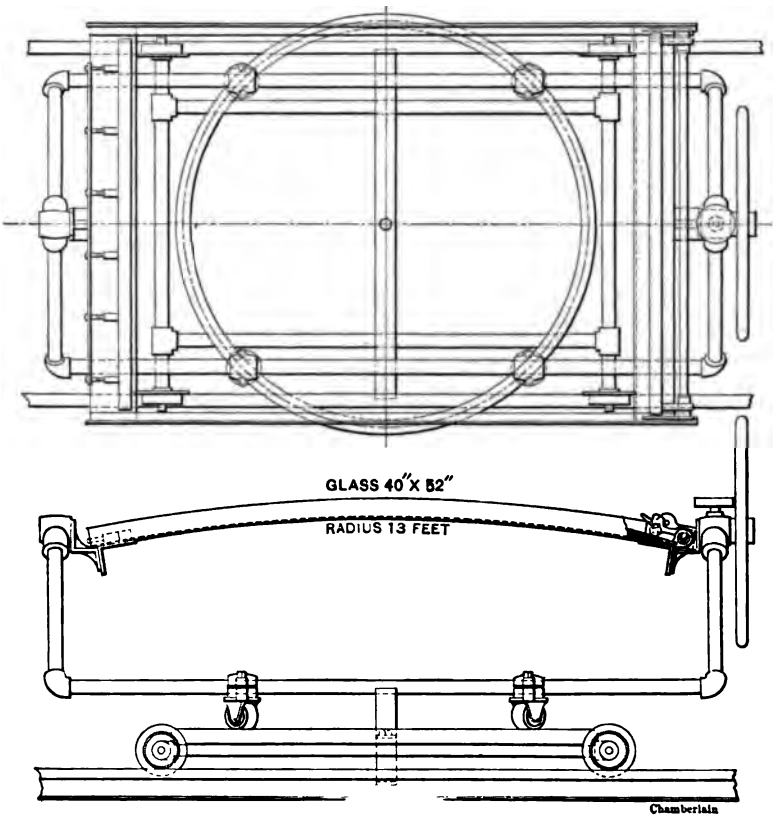


FIG. 220.

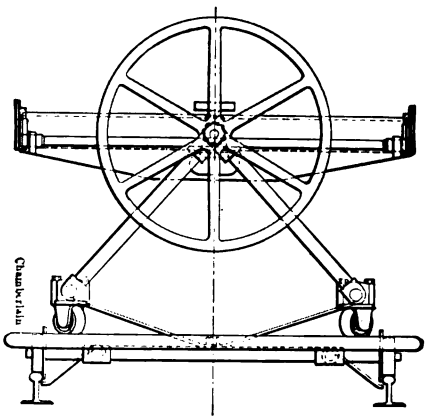


FIG. 221.

FIG. 222.

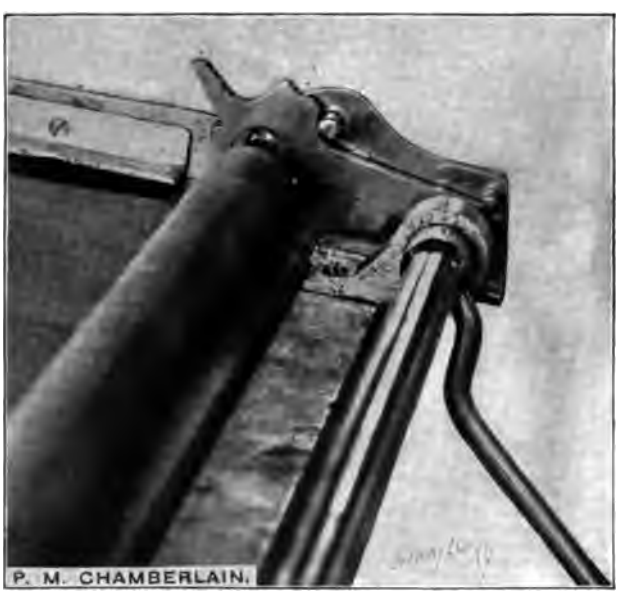


FIG. 223.

FIG. 224.

over, the car pushed out of the window, and the frame adjusted to the proper angle with the sun's rays. The operation is rapid; the placing of tracings very easy, and the contact obtained between tracing and paper all that could be desired.

Three years of use have demonstrated its convenience and durability.

No. 848.*

ON THE VALUE OF A HORSE-POWER.

BY GEORGE I. ROCKWOOD, WORCESTER, MASS.
(Member of the Society.)

FOR a period of several months last year the question, "What is a horse-power worth?" was a burning one in Worcester, Mass.

On June 21, 1895, the city of Worcester took for its own use the waters of Kettle Brook, an affluent of the Blackstone River. The Blackstone River is a small stream flowing from Worcester to Providence, R. I., and passing in 57 miles the premises of 67 owners of 80 developed water privileges, besides a few which are not developed. The total of the heads of water at all the privileges amounts to some 827 feet in that short distance. The quantity of water diverted averages throughout the year in the vicinity of 5,500,000 gallons in twenty-four hours.

It proved to be impossible for the city officials and the mill owners to agree by themselves upon a fair compensation for the loss of water at these 80 privileges, so these owners combined their interests and brought suit against the city of Worcester for damages, partly for the loss in one or two cases of mill ponds and entire mill villages, but mainly for the loss of power occasioned to them by the diversion of the water from their mills into the reservoirs of Worcester.

About 1,000 horse-power for eleven months each year was perhaps the total quantity of power lost, according to the estimates of the hydraulic engineers on both sides. They were not in precise agreement as to the amount, partly because, owing to a peculiarity in the grade of the water-shed above the point of taking, they could not agree on its extent as intended in the Act by which it was taken; but also because of a difficulty in proving the actual depth of the rainfall on this water-shed, and because of the possibility (to the legal mind, at any rate) that a given water power, which, in point of fact, was improved by the regu-

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

lating effect of certain mill ponds situated above it, was not legally worth any more on that account than it would be if they were not in existence, if—as was true—the owner of the power privilege was not also an owner of the said mill ponds. The largest loss of power at any one privilege was about 66 horse-power, and the smallest loss was a fraction of 1 horse-power.

The cases were tried before what, in the description, might seem an ideal commission of three judges appointed as a Board of Arbitration. One was a lawyer experienced in water cases; another was a manufacturer and large user of water power, and the third was an hydraulic engineer. This commission sat during 1898, the trial lasting for some fifty regular days. Scores of witnesses were examined, and each side employed about a dozen eminent mechanical and civil engineers to give expert testimony as to the facts relating to the amount of water taken and power lost, and, particularly, *as to the value of a horse-power.* The Commission has given its opinion, and on June 28, 1899—just four years after the taking—a settlement was effected between the city and the petitioners amounting to $500,000, with interest for four years at 6 per cent. per annum. The exact sum was $615,259.

Unfortunately, the opinion rendered by the commissioners contains nothing of importance to those engineers who have to appraise water-power privileges, and in this respect is unworthy of the importance of the trial and of the opportunity afforded them—at great expense to the public—of elucidating the obscure legal and scientific truths which would have been applicable in the future to similar cases. Perhaps it should be said, in fairness to the commissioners, that it is unusual for such a tribunal to give out the reasons for its findings. Boards of arbitration must follow and merely apply, but not create, the law as defined in the decisions of the regular courts. All engineers, however, will find the evidence introduced by the expert witnesses on both sides of the utmost interest and importance. The occasion for this paper is found in the fact that it was possible, even at this day, for the counsel for each party to the trial—the petitioners for damages and the city of Worcester, each acting on the advice of its expert engineers—to take diametrically opposite views of the true way to estimate the value of the power lost by the diversion. The lack of agreement was fundamental. The two theories cannot be reconciled; yet they were advanced with entire confidence

and unanimity, each by its own adherents. Throughout the taking of testimony, the delivery of the arguments, and, as far as one can see, in the decision itself—which was a blind compromise —both parties succeeded in maintaining their original positions, and, doubtless, were sincere in doing so.

The names of the men who testified to the value of power are, for the most part, to be found in the roster either of this society or of its sister society of civil engineers, and are a guarantee of their fitness as expert witnesses. Among them are to be found:

For the Petitioners.	*For the Defendant.*
Charles A. Allen, C. E.	Desmond FitzGerald, C. E.
T. Herbert Shedd, C. E.	Samuel M. Gray, C. E.
J. M. Whitham, M. E.	Francis W. Dean, M. E.
William Kent, M. E.	Charles T. Main, M. E.
Charles R. Makepeace, M. E.	Prof. James E. Denton, M. E.
Samuel M. Green, M. E.	Stephen Greene, M. E.

Dr. Charles E. Emery also worked on the case in the employ of the petitioners, for some time before his death, and held to their theory. Many other able engineers and commercial witnesses besides those named testified on one side or the other. Undoubtedly—and this is the wonderful thing about this trial—undoubtedly, at this very moment, each side still considers the other to be most obviously in the wrong! This is, of course, highly unsatisfactory from an engineering point of view, though, perhaps, not unusual, considered from the legal standpoint. Is it not within the scope of the privileges of this society to consider and define, by means of a committee, what the correct course of inquiry in such cases should be?

Let us follow in brief outline the course of reasoning adopted by the petitioners in these suits. Their chief syllogism, divested of all its refinements, was as follows:

1. A horse-power is a piece of property—a commodity—which may be considered as "on the market," and hence as having a definite market value, known to those who deal in it.

2. The owner of each of the 80 privileges has lost forever by the act of the city a certain definite number of horse-powers.

3. The financial injury done this owner, therefore, may be found by simply multiplying the market value of 1 horse-power by the number taken from him.

The damage for the mere use of the water for power, as assessed in this way by both the expert and the commercial witnesses for

the petitioners, amounted in the aggregate to a sum variously estimated at from $1,300,000 to $1,800,000. These sums were many times larger than the amount of money admitted to be just compensation by the witnesses for the defendant. In reply to the theory of the petitioners, they argued that in point of fact the petitioners had not been deprived of any "horse-powers," and that really there is no such commodity known as a horse-power. The thing which the owners had lost by the diversion of water from their premises was not even the ownership of the water itself, but simply an easement to their estates; namely, the right to have the water come down through their premises from above in order that they might make any reasonable use of it, *in transitu*, which should not appreciably diminish its flow through those premises to others below them. It was used largely, by each manufacturer, for generating power at a turbine. Counsel for the city argued that the way to estimate the value of this use of the water to each petitioner was, first, to ascertain the exact extent to which the water was available for power throughout the year at each privilege; and, then, to estimate the cost of substituting other practicable and economical means of generating power to the same extent and at each privilege. This computation should give at least the *highest possible* annual value to this use of the water, but, in certain cases, it might exceed the actual loss sustained by the petitioner. Such a case would arise, for instance, where the waterfall was situated in a locality so remote from transportation facilities as to make it difficult to find a purchaser of the privilege at any price, even if already developed.

The witnesses for the defence also claimed that, as none of the "horse-powers" of which an owner was deprived by the act of the city could have been sold anywhere except at the particular place where the falling water *could be used as it fell* (the only right, they maintained, with which the city interfered) to generate power, because that spot was the only one where the water could be used, whether for power or for other reasonable use, therefore, there can be no such thing (considered apart from the market value of the privilege itself) as the *market value* of a horse-power resulting from this use, equally applicable to each unit of power wherever generated on this river. A horse-power, being a unit of activity, not taxed, intangible, could not be a piece of property; but it was a property of a piece of machinery; and hence the theory of the petitioners must be a piece of folly.

Whether or not the theory of the defence is a refutation of the other theory, it is true that the cross-examining attorney for the petitioners caused most of the witnesses for the city to flounder in a quagmire of confusion from which they seemed unable to extricate themselves. It is likely that this was no fault of these witnesses, but rather it was due to the, at present, confused state of the art of estimating such damages. The court has established in Massachusetts that the true value of a property is its fair market value, as between a willing buyer and a willing seller. This proposition was continually harped upon by counsel and witnesses on both sides. The petitioners claimed they were establishing, out of the mouths of their engineering witnesses, the fair market value of power; that is, of a horse-power. One of them stated this fairly enough. He said he had examined the steam and water-power plants at 25 of the mills.

(Page 1413 of Testimony.)

Q. What did you make the average cost of producing that quantity of horse-power?

A. I made the average cost of producing the horse-power diverted $50.14 per horse-power per year for the twenty-five mills.

Q. Do I understand that this calculation of yours is based on your own information as to the cost of producing power with the appliances that they had?

A. Yes; with the appliances under the conditions they were running.

Q. What is your opinion as to the fair value of horse-power per year at these various mills?

A. The fair market value of the horse-power at the different mills I should consider to be $50 per horse-power per year.

Q. I should like to have you state, if you will, unless you have covered it already in your testimony, the elements that you took into account in coming to that conclusion.

A. The market value of a horse-power, as with anything else, is what a man willing to sell horse-power would sell it for to a man willing to buy. That is an old definition, so that the rental value of horse-power as actually rented forms one of the elements on which to arrive at market value. The cost of producing horse-power or anything else has also some relation to the market value, insomuch that the market value will generally be not very far distant from the average cost. One man may produce horse-power which will cost him more than he could sell it for. Another man might produce it at less than he could rent it for, but the market value usually has some relation to the average cost. But market value generally will never fall for a long time below the average cost, for if it does, people will stop making it. It may go above it, giving profits for some time. If it got too high more people would furnish it. The market value also depends on supply and demand. If you could make horse-power cheap, it might not be salable on account of there being no demand. So in the case of this valley we took into consideration the fact that there is a perpetual demand for a large

amount of horse-power all the time through the whole valley—that there is a market for the horse-power, that manufactories are here which require and which will always be likely to require power. The market being established, there is a demand for it. The condition of the manufactories along the valley showing that they are well located for the production of the goods they are making, the location with reference to markets, railroad lines and cities, all come into fixing the market value of horse-power. Rental and the possibility of reduction of rental in times to come—the average cost under ordinary commercial conditions, the individual cost varying through a wide range—the average cost comes at about $50, and taking all these elements into consideration, the nearest figure I could come to the market value of horse-power is $50 per horse-power per year.

Q. Have you an opinion as to the practicability and economy of using water power in connection with steam power with a view to saving money?

A. Yes; whenever there is a water power available on such a stream as the Blackstone River, wherever there is water power it ought to be utilized. In all cases I know of, it is better to put in wheels and utilize the water power than let it run to waste. If a man owns a water privilege he had better use it than put in steam. Or if he has a mill where the water power is not enough to run the whole plant, he should use the water power as far as he can, and use steam to make up the difference. That opinion is largely favored by the fact that all the mills I have seen are using water power. They have steam plants large enough to run the whole mill, but they use water power as much as possible, and steam power as little as possible.

So this witness for the petitioners specifically states that a horse-power is property which may be sold, and which has an established market value, which value must be somewhere near its cost of production by steam, in a given locality like that of these 80 privileges. He is troubled by no misgivings such as are outlined above in the theory of the defence. He does not relate the financial injury, caused by the diversion of water, to the mill properties at all—that is, he does not allude to what they may have been worth before and what after the diversion. He does not say anything about easements. A man who loses 1 horse-power from a 20 horse-power fall is damaged to just the same extent as he who loses 1 horse-power from a 1,000 horse-power fall, even if—as was true in the Blackstone River mills—the one needs a 20-horse engine, with slide valve and throttling governor, to balance the inequalities of his 20-horse water power, while the other uses a 1,000 horse-power engine to balance the inequalities of his water power. That is to say, even if one man will lose $100 per annum—the cost of maintaining 1 horse-power with his engine—by the diversion, while the other will lose $15 per annum, the one is to receive as fair compensation but $50, while the other makes a net gain—in the operation of this theory—of $35

per annum, and is in the market to "lose" more "horse-powers" at the same gainful rate. Moreover, the variations in the cost of coal up and down the stream is also immaterial, although it was as high as $4.60 at the source and as low as $3 at Pawtucket. According to this theory—let the $3 purchaser chuckle and the $4.60 man murmur—the *market price* of a horse-power "goes." These were the reflections of counsel for the defence. His witnesses testified, one after the other, that the damage, or financial injury, done the petitioners was certainly not greater than a sum of money the interest of which would enable them to produce the lost power by other means; that the fact was that every one of the mill owners owned and operated a steam plant large enough, or nearly large enough, to carry the entire mill load; and that what these mill owners would do in future, as, in fact, they had done since the diversion, would be to carry the load, formerly driven most of the time by the lost water, continuously on their steam engines; and that hence a coal pile large enough to do this, if freely supplied to them, would place them in as favorable a position to carry on the business of manufacturing goods as they ever enjoyed. Some said they should also be allowed supplies, as waste, and oil, and labor. Still others thought they should, further, be allowed a part of the interest, depreciation, taxes, and repairs on the steam plant; such a part of the whole amount of these items as the lost power bore to the entire power of the engine. One witness for the city thought that enough was not made of the benefit it would be to these engines, large and small, in the direction of smooth working, to carry continuously an additional load, thus allowing their valve gears to work more normally than before the diversion. He also called attention to the generally accepted belief that the friction of an engine was independent of the external load, so that, as it is friction that wears out an engine, no extra use of the mechanism was imposed on the mill owner as a result of driving the greater load. This witness favored compensation on a coal-cost basis, in view of the fact that as (according to the testimony of the hydraulic engineer retained by the city) the flow of water was liable to cease almost entirely at certain times in extra dry years, therefore no one of these privileges was of any considerable value unless operated in conjunction with a steam plant of a size at least three-quarters of the greatest available power of the privilege. This was corroborated by the observed fact that in nearly every mill a steam-power plant as large as, or larger than,

this size, was at work all the year around. He testified, in effect, that the water privileges in New England which maintained a flow of water sufficient to drive a mill constantly all the year round could be counted on the fingers of a man's hands, and that none such could be found on either Kettle Brook or the Blackstone.

It was right at this point in the testimony of witnesses for the city that the edge of the quagmire of confusion, alluded to above, was encountered by them. Mr. Goulding, attorney for the petitioners, sought to have the city's witnesses admit frankly that a "water power" was itself property; then that any subdivision of it, as 1 horse-power, was also property. If he could do that then his side would win, for the "fair market value" shibboleth would become operative. Not the *cost* of making the power, but the *selling value* of it, would be the test of the damage his clients had sustained. He introduced much testimony to show at what price, per horse-power, mechanically or electrically transmitted power was actually sold in the Blackstone Valley. The witnesses for the petitioners freely admitted that the *cost* of producing a horse-power by steam was very different at the different mills; in fact, that there could be no comparison between the cost at the least economical plant and that at the most economical plant. It is probable that no attempt would have been made by them to combine these costs in a class, and average them to find an *average* cost which would serve as the market value, had there not been so many other mills of all sizes to be considered by the tribunal at the same time.

None of the engineering witnesses for the city was willing, however, to subscribe to the theory of the petitioners, even under the compelling influence of Mr. Goulding's leading questions. They would go a little way with him, thus:

CROSS-EXAMINATION OF PROFESSOR DENTON.

(P. 2605 of Testimony.)

Q. If I understand your statement, Professor, your objective was to arrive at the fair market value of the water power diverted?

A. Yes, sir.

. . . . . .

Q. Did you make any inquiries to find out what power rents for in the valley of Kettle Brook and the Blackstone River, or in the vicinity, in such quantities as were diverted? Did you make any of these inquiries?

A. No, sir; I don't think that is a test.

Q. But you were after market value all the time? That was your objective?

A. Yes, market value.

Q. What is the rental value of horse-power in New York by steam, under circumstances of renting power by steam, in quantities, say like this of the Darling Woollen Mills, where you call the diversion 27.9 horse-power?

A. You get your power from some steam engine over some shafting. Such power is rented for about $75 per year per horse-power.

Q. Do you know what the rental value of it is by electricity?

A. It runs from that to a little higher.

(Mr. Goulding has seemingly carried the witness with him thus far, but he soon gets off the track which leads to the admission of an established market value for a horse-power.)

. . . . . .

A. . . . Every water power's value is fixed by some engine.

Q. By some engine?

A. By some engine. It has to be considered in relation thereto if there is a purchase or sale. If you are going to buy up a water power, spend money for it, you have got to consider what you can afford; you have got to consider whether you can afford to spend a certain sum of money for water power rather than use some steam plant.

Q. Do you say the water power of Niagara Falls is measured by some steam engine?

A. Why, surely it is! They have to compete with Buffalo steam prices, and they are starving on it now.

. . . . . .

(Mr. Goulding now brings to bear the big guns in his forward turret, so to speak:)

Q. I understand you to be considering the question of the value of power from the point of view of the producer. Now, suppose you take the point of view of the consumer, who pays to the Woonsocket Electric Power and Machine Co. $54 a year. There is so much that he pays for power. How does it happen that you can take away the horse-power from this company without paying what it brings right there in the market every day?

A. We are not dealing with that consumer, but we are dealing with the owners of this power and considering what they can afford to sell that power for as a whole.

Q. I am considering the market value, and I understand you are one of the witnesses on the part of the city to get at the market value. I put before you the supposition that the consumers pay $54 a year one after another, and I ask you if the city of Worcester took away from the consumer in Woonsocket this power, why it should not pay what is paid there?

A. I don't see why it should pay to the owner anything but a reasonable profit.

(The big gun of "fair market value" is now fired off:)

Q. Any other property taken away from anybody, I suppose, you would say as a matter of justice ought to be paid for at the market value. What is the reason

that horse-power is taken out of the category of things whose value is determined at what it brings day after day in the market?

A. Now, my general answer to that is that everything that is sold brings what it cost, plus a reasonable percentage of profit; and what it cost in this case is identified by what this property would sell for; and that I have allowed all I can see it does sell for, and a profit on top of that. I don't consider the electricity on top of that water power. I am looking at the water power, stopping at the wheel.

. . . . . .

Q. Is there any other thing in the universe that is estimated in any such way, according to your knowledge? If a man's property is taken away from him, don't he get what it is fairly worth and what he can sell it for in the market? I use the terms as meaning the same thing, as they do mean the same thing in law and in common sense.

A. The price—

Q. Is there anything else—clothing, horses, anything? A man has got 100 horses here in Worcester. Somebody comes along and takes away 50 of them; he is liable to him for doing it. Now, the horses, we will assume, are worth $100 apiece in Worcester in the market. Are his damages—ought he to have $100 apiece for those horses or $50 apiece, because he has got a ranch somewhere in the West where he can produce them and get them to Worcester for $50?

Whether or not Professor Denton would have answered this question satisfactorily, without compromising his previous testimony, it is impossible to say, because he did not hear it correctly, and hence his answers were somewhat irrelevant. It is a fact that Mr. Goulding succeeded in mixing up nearly every one of the city's witnesses by propounding to them the same question. They were convinced by their own logic; but they were convicted by his. One witness backed away from the question by remarking that he had not qualified as an expert on horses.

When, however, the witness is off the stand, and in the quiet of his own fireside, it does not seem difficult to point out the real bearing of Mr. Goulding's question on the theory of the defence. A man has on sale a horse, fairly worth in the market twice what it cost him. If the horse is taken by the State, it is the law in Massachusetts that the State shall pay, as damages, not what it cost the man, but what he could naturally have sold it for. Mr. Goulding meant to have the city's witnesses substitute a horse-power for the horse, in his illustration. The conclusion would then be irresistible that the *cost* of producing a horse-power was not the measure of the petitioner's damage. Instead of depending on the cost, the damage would depend on what a horse-power could be sold for in the horse-power market. Now, the defence claimed from the beginning that no horse-power had been taken. Water had been taken. But the petitioners only possessed the

right to extract energy from that water, perpetually falling at their premises. In diverting the water the city took away this right. Then why should the city not pay the fair market value of this right? In truth, it is this right, according to the theory of the defence, that is represented in Mr. Goulding's illustration by the horse taken by the State; and this right is technically described as an easement to an estate.

How shall the fair market value of this easement be determined?

Generally speaking, it is impossible to cipher out, with mathematical accuracy, the fair market value of an easement. "Commercial" witnesses are called in to express their opinions of the value of the estate before the easement was taken, and the value left to the estate after being deprived of the easement. The difference is the value lost by the estate. That is to say, it is the fair market value of the easement.

It so happens that in the case of the particular kind of easement we are considering, it is possible to prove, by mathematics and data in the possession of qualified engineers, that its value *cannot exceed* a certain fairly definite, annually received, sum of money. Its actual value may easily be some lesser amount than this limiting value. The reason is that when the work is done by Nature, it must be done in a particular locality; while if done artificially—*i. e.*, by the combustion of coal—a great advantage is gained in being able to select a site for manufacturing purposes unhampered by a lack of water for power.

If each petitioner were supplied perpetually with coal in sufficient daily quantities to provide the same quantity of energy at a steam-engine flywheel as was yielded at the water-wheel shaft by the water diverted, he would obviously be fully compensated for his loss, other things being equal, and perhaps much more than fully compensated. But other things are not equal, and he may require a further sum before his total loss is made entirely good to him. How much this extra sum will be must depend upon conditions, which will vary with every case, respecting the amount of water diverted; the maximum and minimum flow of the water before and after the taking; the size of the water power, and the size of the necessary auxiliary steam plant. It may be that the quantity diverted is so large a proportion of the whole as to leave no value to what remains; or that the turbines formerly used were too large to be used efficiently after diversion. These are details of relatively insignificant importance.

The fact is that the greatest cause of the disagreement between the two sides, in the Kettle Brook water cases, is traceable to the lack of positive knowledge, on the part of both sides, as to the actual available quantity of water flowing each day in the year at each privilege. The petitioners claimed that the amount was 5,500,000 gallons per day throughout the working days in the year; that is to say, it was a fixed and invariable quantity. But while the civil engineers, who testified for the city, allowed 5,500,000 as the correct figure for the *average* flow, they claimed that there were frequently whole days when there was practically no flow of water at all.

Now, if the flow was fixed and invariable in amount, before the taking, then the average annual damage per horse-power, $50, assessed by the steam engineers who worked on that hypothesis was correct, even if judged by the theory of the city's witnesses. They would admit, that is, that it would cost, on an average, that much per annum to develop a horse-power by steam at the average of these privileges. The steam-engineering experts for the city, however, assumed that the flow of water at each privilege was so unsteady as to make a steam plant necessary, if the water power were to be used at all; hence only coal was saved by this use of the water.

The theory of the experts for the petitioners, that a horse-power is a commodity with a fixed value at any point save right at the point where it is generated, seems to the writer absolutely erroneous. He, however, testified on behalf of the city, under the influence of her senior counsel, Senator Hoar. Messrs. Kent and Whitham are of the precisely opposite opinion; but then, they could not shake off the compelling candor of Mr. Goulding.

This Society has listened to several papers on the value of water-power privileges. Mr. Charles T. Main, especially, has dealt recently with the subject in what seems to the writer to be a clear and comprehensive paper, to be found in Vol. XIX. of the *Transactions*. But these papers were equally accessible to the witnesses on both sides at this trial, and Mr. Main himself was a witness on behalf of the city, yet with no conclusive result. Meanwhile the water boards of our cities are acquiring, by legislative processes, stream after stream now yielding water power for industrial purposes; and it is of great financial importance to mill owners and water commissioners alike for engineers to have a united rational opinion as to the true way to estimate the value of a water-power privilege.

APPENDIX.

REPORT OF COMMISSIONERS IN KETTLE BROOK AND BLACKSTONE VALLEY MILLS.

To the Honorable the Justices of the Superior Court:

We respectfully report, after hearing all the parties in interest, that we have entered a finding of damages in the cases referred to us under the order of this Court, and which appear upon the accompanying schedule, and make this report, covering, we think, all questions raised at the hearing, for what use it may be to the Court and to the parties in interest.

The city of Worcester, acting under Chapter 384, Acts of 1895, and its record taking, made June 21, 1895, appropriated the waters of Kettle Brook, the water rights connected therewith, a mill, its outbuildings and appurtenances, certain lands, ponds, and reservoirs, and all above the point where the city diverted the water into its distributing system from the reservoir at Kent's mill, so called.

Below this point Wait's reservoir received the water diverted, and transmitted it to the mill privileges located upon Kettle Brook and upon Blackstone River, into which the brook runs. This waterway is some fifty-seven miles in length from its source in Arnold's pond to the mouth of the Blackstone River in Pawtucket, R. I.

The amount of power required to run the mills varies from about 20 to 2,000 horse-power. This has been secured by utilizing the water coming from the brook and the other sources below, and in most cases employing the same in conjunction with steam-engines. A few of the mills have been run by water alone. The water diverted has been a valuable adjunct, and its loss depreciates the market value of the property affected.

We propose to examine the premises seriatim from the source of the brook to the mouth of the river.

1. Arnold's pond contains sixty-four acres, and has a pondage capacity of about 70,000,000 gallons. This, and also Bottomly or Paxton pond, the Mann and Marshall pond, Kent pond, and some small ponds that are also located above the point of diversion, were reservoirs to be filled with water during the wet seasons for use during the dry, in order that the supply to the mills

should be as uniform as was practicable during the entire year.

The petitioners regulated to some extent the run-off of the reservoired water from Arnold's pond, but for the use of all the mills below. They claimed that the value of this pond was enhanced in June, 1895, because it had become valuable in the market to hold and supply water for domestic purposes.

We disallowed this claim, as the cost of the excavation of the pond, and other expenses necessary to render the premises fit to store water for that purpose, would equal, if not exceed, the value of such enhancement, and award as damages the interest of the petitioners in the premises, prepared and established as a water right for mill purposes, and no damages for water collected there other than the effect of the loss of the water at their mills below, which they used in common with the other mills.

2. Between Arnold's and Bottomly or Paxton pond, the stream runs through an undeveloped privilege to Bottomly or Paxton pond.

3. This pond has a pondage capacity of about 400,000,000 gallons and an area of from 105 to 115 acres. Its dam was raised and enlarged by an agreement made in 1852, hereinafter referred to, and the water has been reservoired and used since that date by means of this dam for mill purposes alone. In 1876 the dam was repaired and strengthened. In June, 1895, it was well adapted from its location, height above the sea, character of its bottom and shores, and for other reasons, to hold and preserve water and become part of a distributing system for domestic supply. Whether the city intended to exercise its power to take Kettle Brook was problematical until its action of June, 1895. Any enhancement growing out of its action, or proposed action, was not urged by the petitioners to enhance the damages; but they claimed that while the city had such a right, it was one in abeyance which it might never exercise, and this would not preclude the petitioners or any one else from obtaining a charter to use it for domestic purposes. The petitioners owned the land covered by the pond, and the dam and other appurtenances, in fee. They had no other interest in the water gathered at this pond than to use it in common with the mill owners below at their mills. If any water company had taken it before the city, all the mill owners below could have collected damages for the diversion of the water.

The petitioners offered the evidence of two experts, one of whom had been the city engineer of Worcester for many years, tending to show that there was such a chance and probability that the pond would be taken for domestic purposes, other than by the city, in 1895; that it entered to some extent into the market value, and should be considered in valuing the petitioners' interest, and in passing upon all the uses to which this interest might be properly and profitably applied at this time.

It is apparent that whoever bought this pond, even if he was equipped with a charter to supply water for domestic purposes, would not in all probability have paid the price for it that he expected to get from his customers in selling its water by retail, but would have bought and paid for it in bulk; and whether it would have been sold within a reasonable time after 1895 for such purpose was a probability and not an actuality; that there was no such customer with a charter in existence; that the claims for mill owners' damages were very large, and, for the reason that these were necessarily problematical until after determination, would naturally depreciate the selling value of the property.

On account of the question depending upon the conditions and chances already stated, and the rule that we must not exceed the fair market value, any enhancement arising from this cause is comparatively small to that which it would have been if these conditions had been fixed and certain.

4. Below Paxton pond the city took the land of W. M. Olney *et al.*, which consisted of a sawmill privilege, the land under the mill pond and adjacent thereto amounting to some fourteen acres, together with an unoccupied water privilege. Passing from the Olney land the brook ran through the property of Leicester, which had an area of some 200 acres. The action of the city cuts off this farm from access to the brook, and subjects the remaining part to other damages.

5. Below the Leicester premises, the stream runs through the manufactory property of George Mann *et al.* The petitioners owned some 300 acres of land, mostly employed for farming purposes, in the midst of which they had built, and were carrying on business in, at the time of the diversion, a satinet mill with machinery and other necessary appliances. Connected with this plant were tenements and other buildings required in their business. They had dammed up the brook above the mill, creating a pond with a capacity of about 45,000,000 gallons.

The city took a developed water privilege used in connection with the mill and two undeveloped privileges; it also took ten rods of land, in width, about the shores of the pond, together with the land under the pond, which had an area of about twenty-four acres. It claimed that its taking did not include the mill or any other buildings upon the premises except a small fraction of one of them.

By the terms of the record taking, the city took ten rods of land around each pond or reservoir above the point of diversion. In this particular case the pond was so built that its dam, instead of running across the stream and holding the pond up, and then running the water to the mill by pipe or other contrivance, was so placed as to bring the pond within ten rods of the mill as well as some of the other buildings, as indicated upon the plan.

The claim made at this mill for enhancement of its market value on account of the pond being adapted for domestic purposes we disallowed, and found, as in all other cases above the point of taking, that the damage to the petitioners is the market value of the property so taken, and the effect upon the remaining property on account of the same.

6. By the terms of its taking, June 21, 1895, the city took all the water of the brook above Kent's mill, and has since that time actually diverted it at this privilege by running it through its pipes into the city, and no part of it has been returned to the stream below except as hereinafter referred to as returned water.

The parties practically agree that if Peter Brook, so-called, was to be included within the watershed the amount of the same would be 2,627 acres, and the annual yield during an average year would be a little in excess of 1,500,000,000 gallons.

Whether Peter Brook, whose watershed has an area of about one-half square mile, was a part of the shed was much in dispute. The divide between Kettle Brook shed and the adjacent one was difficult to define, but upon a careful consideration of the testimony and examination of the premises, we have concluded that a substantial part of the water, *i. e.*, one-half, particularly during the wet season, runs from Peter Brook into Kettle Brook and is a part of the water taken by the city.

7. From the point of diversion, the water ran down the stream to Wait's reservoir, from whence, in common with the water that

had gathered in that reservoir from the watershed between it and the Kent mill, it was delivered to the mills below.

Ever since an award was made in 1883, determining the amount of water to be delivered daily from this reservoir, the water has been regulated so as to furnish, as near as can be, a daily supply of 5,500,000 gallons, which has been used for the common benefit of all the mills below.

8. All the mills affected, except that at the Mann and Marshall privilege, are located below Wait's reservoir. As to those located in Cherry Valley, *i. e.*, the first mills below Wait's reservoir, the loss deprives them of nearly all the water that they had for power and also for washing and other manufacturing purposes, and has affected the value of the water left in the stream, which is derived from the watershed below Kent's mill.

Below and including the mill upon the schedule known as the Jamesville Mill down to the mouth of the Blackstone River, the mills receive ample water from their other sources for manufacturing purposes, and the loss suffered here is in power alone. The water from the other sources increases in volume as the mouth of the river is approached, and is the means of contributing a very large fraction of the water employed.

The water which came from Kettle Brook was more carefully reservoired than much of the water below, and in proportion to a large percentage of the same was of more relative importance, but the water from the brook was a small fraction in comparison to what could be obtained from these other sources, particularly near the mouth of the river.

9. At least 65 per cent. of the water diverted by the city from Kettle Brook returns through the main sewer of the sewerage system of the city to the river, some miles below the point of diversion. This returned water runs by all the mills on the river from and including the Worcester and Suburban Street Railway Company upon the schedule. The city has been, and is, engaged in the attempt to free the water from sewage pollution. It did not appear whether or not it had been altogether successful in so doing, or whether, considering the probable increase in the use of its sewerage system, or for any other reason, it could eliminate all pollution from the water so returned.

The city made no reservation in its taking which in any way gives the mill owners the right to use of this returned water. It took all the water of the brook as and for itself, and so far as

the mill owners are concerned, may do with it whatever it pleases. The use of the mill owners to the same is only permissive, and could at any time be withdrawn by the city, and it may change its present mode of disposing of the sewage by using a pipe down to tide water, or by adopting any other change, which it may at its election. The mill owners must recover their damages once for all. They not only have no title to use it, but cannot, in the event of a sale, give any title to the same to their purchaser. The probability of future continuance is too speculative, as we think, for us to base any estimation upon, and following the rule adopted in Proprietors of Mills *v.* Braintree, 157 Mass. 345, and other cases, we have not considered the returned water in estimation of mitigation of damages.

10. While it is true that the reservoirs above Kent's mill were built and maintained by some or all of the mill owners in the upper part of the stream, known as Cherry Valley, yet those below, as far as it can be determined, have always had the benefit derived from any reservations made of the same, and were enjoying the same at the time that the city made its diversion.

We were asked to take into consideration the fact that the dams at these ponds might have been taken out at any time and the natural condition of the stream restored, so far as it was practicable, and as the lower mill owners could not prevent the same, they would have no further benefit derived from the water than this natural flow.

We took the same into account, but in view of all the facts, were satisfied that it did not affect the market value of the property, and allowed damages to each mill owner for the amount of power that he was obtaining, or could profitably obtain, at his mill property from the water as reservoired and run by him at the time of diversion.

The rule of law, as we understand it, provides that while the mill owner has, unless he loses it by grant or otherwise, the right to the natural flow of the stream, he is also entitled to any benefit that arises by reason of any mill owners creating reservoirs upstream.

11. Wait's reservoir, which received all the water diverted and delivered it as uniformly as was practicable, considering the amount of water flowing in the stream in very wet weather, by the act of the city loses all its stored water except from about one square mile of watershed, and even then, unless the same

can be filtered as a protection against the pollution that arises from the use of the stream, for manufacturing purposes will be of little, if any, value.

We have followed the rule in assessing damages in this case in Watuppa Reservoir Co. *v.* Fall River, 154 Mass. 267, and Proprietors of Mills *v.* Braintree, 157 Mass. 345, and allowed the reservoir corporation damages to its dam, and the land which it owned and which it flowed for this purpose, and other property, caused by taking the waters of the stream, and have assessed to the mill owners below the damages accruing to them respectively by reason of the diversion of this water so regulated by the ponds and Wait's reservoir, *i. e.*, as it was run by their mills at the time of the diversion by the city.

12. The mills at Cherry Valley, *i. e.*, all those located between the Darling Shoddy Mill, so called, the first mill below Wait's reservoir, and the Jamesville mill, had but a comparatively small amount of water left in the stream after the diversion. This rendered the question of where they were to obtain water for manufacturing purposes, other than power—an important one. After a careful examination, however, we are satisfied that with the flow from the watershed below this reservoir during a part of the wet weather, and the amount that can be collected and reserved from the square mile of watershed, the waters of which run into Wait's reservoir below the point of diversion, and by use of filters at each of these mills, sufficient water can be obtained for such purposes to supply the mills as at present, or as they are likely to be equipped.

In estimating the damages at these mills, we have considered,

First. The value of the water diverted, taking into account the fact that a part was used for power and the remainder for other manufacturing purposes, and valuing the latter at what it would cost to reproduce and maintain.

Second. The loss in power sustained by using any part of the water not diverted for such reproduction.

Third. The effect upon the value in use for power upon the remaining water after making the deductions referred to in one and two.

13. We have awarded as damages to the mills, below the point of taking, the depreciation in their fair market value on account of diverting from them the water taken by the city.

So far as these properties are concerned, the petitioners

claimed that inasmuch as the city had taken a certain amount of power from each mill, that was worth in the market so much per annum, the rule to be employed is to find the amount of power taken at each mill, multiply by its value per horse-power, capitalize at 4 per cent., and the same is to be treated as the damage so far as the loss of power is concerned. It is urged that this is the only just method, because that was what the power was worth in the market if sold in 1895, and the city must pay the market value.

The respondent claimed in effect, among other things, that assessing damages upon the basis of capitalization was erroneous unless its value was put upon an exact proportion to that which it bore to the entire property affected; that if the going rate of power in lots equal to that taken was to be employed, that should be treated as an element alone, and regard be had to all the conditions existing to determine how much this valuation was to be affected; that upon the question of capitalization we should consider how much, by employing cheaper methods to obtain power, its cost would be lessened.

We excluded evidence offered by the respondent as to the cost of creating similar mills and powers at more favoring manufacturing centres, and then by comparison showing how much less the property of the petitioner was worth, as in no way aiding us in the determination of the damages. We have sought to ascertain the actual condition of the property as it was in 1895, and how much water power had been, and how much might be, profitably and practically developed.

In passing upon this question we have considered the amount of horse-power lost, and its value, in relation to each property, as the most important element, and have also examined the property in its entirety, the relative value of the power taken to the whole estate, the location, capacity, adaptability, conditions, the water in the reservoirs at the time of the taking, and all other factors relating to each property, in order to determine how much less the property was fairly worth in the market after taking all this into account.

We have awarded damages in the premises as per schedule annexed with interest from the time of the taking, June 21, 1895.

E. C. BUMPUS,
WILLIAM WHITING,
GEORGE E. EVANS,
Commissioners.

EXHIBIT C.

No. of Case in Court.	Name of Petitioner.	Property Affected.	Amount of Damages.
2458	E. D. Thayer *et al.*	(*a*) Arnold reservoir	$3,950 00
"	" " "	(*b*) " mill privilege.	
2032	" " "	Paxton reservoir	36,750 00
2028	Town of Leicester	Undeveloped privilege and land	1,890 00
2027	Geo. Mann *et al.*	(*a*) Mann & Marshall mill and other premises	66,000 00
"	" " "	(*b*) Mann Bros.' undeveloped privilege, between reservoir and mill pond.	
"	" " "	(*c*) Mann Bros.' mill pond and mill privilege.	
"	" " "	(*d*) Mann Bros.' undeveloped privilege below mill.	
2033	Leicester Water Power Co.	Waite reservoir	5,250 00
1897	A. W. Darling, lessee	Darling Shoddy Mill or Bottomly mill privilege, lease	1,760 00
2612	A. W. Darling *et al.*, lessees	Darling Shoddy Mill or Bottomly mill privilege, lease	862 00
1741	E. D. Thayer, owner	(*a*) Darling Shoddy Mill	30,669 00
"	" " "	(*b*) Bottomly mill privilege.	
"	" " "	(*c*) Undeveloped privilege.	
1742	Newton Darling	Chapel mill privilege	14,671 00
1900	Eli Collier	Collier, formerly Dixon privilege	10,159 00
2034	Waity M. Olney *et al.*	(*a*) Geo. W. Olney privilege.	
"	" " "	(*b*) Watson privilege	36,550 00
"	" " "	(*c*) Sawmill privilege.	
1901	Anjeanette K. Smith	Anjeanette K. Smith mill	26,609 00
1902	Channing Smith, lessee	Smith mill privilege	2,212 00
2029	E. D. Thayer, Jr.	Ashworth & Jones privilege. E. D. Thayer, Jr., privilege.	41,370 00
1898	Albert W. Darling	Darling privilege	15,571 50
1905	Elizabeth A. Butler	Formerly Hunt, now Butler privilege	17,920 25
2443	H. W. King, Trus.	Jamesville	12,618 00
1903	Wm. J. Hogg *et al.*	Stoneville Worsted Company privilege	12,786 00
1906	Albert Curtis	Albert Curtis privilege	4,980 00
1904	Curtis Manufacturing Co.	Curtis Mfg. Co. privilege	6,275 00
2024	Hopeville Mfg. Co.	Hopeville Mfg. Co. privilege	3,215 00
1896	Wm. J. Hogg	Pakachoag mill privilege	4,460 00
1899	Geo. A. Stevens	Stevens, formerly Perry, privilege	5,368 00
2454	Wor. & Sub. St. Ry. Co.	Now Power Station, formerly Burling mill privilege	4,200 00
1801	Anna L. Morse *et al.*	Morse privilege	2,940 00
1802	Wm. Harrington	Atlanta mills privilege	4,620 00

No. of Case in Court.	Name of Petitioner.	Property Affected.	Amount. of Damages.
1803	J. H. Mason & Co.	Millbury cotton mills privilege	4,830 00
1804	Cordis Mills	Cordis Mills privilege	5,460 00
1805	Charles T. Aldrich	Aldrich Mill privilege	5,040 00
1806	Sutton Mfg. Co.	Sutton Mfg. Co. or Wilkinsonville privilege	8,820 00
1807	Saunders Cotton Mills	(*a*) Saunders cotton mill privilege	7,980 00
"	" " "	(*b*) Grist mill privilege.	
1808	Fisher Mfg. Co.	Fisherville privilege	4,410 00
1809	Wm. H. Whitman	Farnumsville cotton mill privilege	3,570 00
1810	Paul Whitin Mfg. Co.	Rockdale privilege	4,830 00
1811	Riverdale Woollen Co.	" "	5,830 00
1812	Calumet Woollen Co.	(*a*) Calumet privilege	8,400 00
"	" " "	(*b*) Hecla privilege.	
1813	Lawrence Felting Co.	Lawrence Felting Co. privilege	6,300 00
1814	Blackstone Mfg. Co.	Blackstone privilege	12,285 00
1815	Earl P. Mason Land Co.	Waterford, Evans & Seagrave privilege.	3,990 00
1816	Edgar K. Ray *et al.*	(*a*) Bartlett privilege	1,648 00
"	" " "	(*b*) Ballou privilege.	
1818	Margaret F. O'Reilly *et al.*	Grist mill privilege	268 50
1817	" " "	Harris Woollen Co. privilege	268 50
1819	Joseph G. Ray *et al*	Lyman mill privilege	446 00
1824	Social Mfg. Co.	Social Mfg. Co. (Globe Mill) privilege	945 00
1822	Woonsocket Electric Machine and Power Co.	(*a*) Main Street Station, No. 1 power station privilege	3,717 00
"	Woonsocket Electric Machine and Power Co.	(*b*) Front St., No. 2 power station privilege.	
1821	Edgar K. Ray *et al.*	Ray Cotton Co. privilege	420 00
1820	Lippitt Woollen Co.	(*a*) Privilege	1,050 00
"	" " "	"	
1827	Geo. H. Baker	Leicester Knitting Co. privilege	210 00
1823	American Worsted Co.	American Worsted Co. privilege	840 00
1825	Eagle Mills	Eagle Mills privilege	1,092 00
1826	Clinton Mfg. Co.	Clinton privilege	1,680 00
1828	Frank Harris	Hamlet mills	3,150 00
1829	Mannville privileges	Mannville privileges	7,980 00
1832	Valley Falls Co.	Albion privilege	4,515 00
1831	Lonsdale Co.	(*a*) Ashton privilege	8,400 00
"	" "	(*b*) Lonsdale No. 1.	
"	" "	(*c*) " No. 4.	
1830	Albion Co.	Valley Falls privilege	5,040 00
1833	Stafford Mfg. Co.	Central Falls privilege	1,680 00
1834	Fred S. Farwell	Farwell Worsted mills, or Central Falls privilege	1,155 00

No. of Case in Court.	Name of Petitioner.	Property Affected.	Amount of Damages.
1835	Pawtucket Hair Cloth Co.	Pawtucket Hair Cloth Co. privilege	1,200 00
1836	Sylvia C. Pitcher	Pitcher mill privilege	525 00
1837	Dexter Yarn Co.	Dexter Yarn Co. Pawtucket privilege	525 00
1838	Job L. Spencer	Old Slater privilege	525 00
1840	Littlefield Mfg. Co.	Littlefield Mfg. Co. privilege	336 00
1843	D. Goff & Sons	D. Goff & Sons lower dam privilege, east side	2,810 00
1841	Chas. B. Paine *et al.*	Paine & Taylor privilege on Sergent's Trench	105 00
1842	Darius L. Goff *et al.*	D. L. & L. B. Goff Pawtucket privileges	3,096 00
1839	Pawtucket Gas Co.	Pawtucket Gas Co. privilege	367 50
	Total		$508,395 25

DISCUSSION.

*Mr. Everett C. Bumpus.**—It may be of some service in connection with the Appendix to Mr. Rockwood's paper, for me to state the rule upon which we proceeded as regards the valuation of these several properties. There were four classes.

First. The water sources which had been supplying the mills with power and which were taken by the city for domestic purposes.

These were valued upon the same principle that one would value a horse or a cart, *i. e.*, a fair cash value dependent upon the evidence.

Second. A mill with land and water-power appurtenant thereto, all of which was taken by the city.

We followed the same rule as in one.

Third. A series of mills that were directly below the point of diversion that were not only dependent upon the water taken for power, but for other manufacturing purposes.

We knew of no other rules so far as these mills were concerned, and have ascertained their market value before the diversion, upon the evidence offered, and the diminution in the same consequent upon the loss of this water.

Fourth. A larger number of mills located upon the stream miles below the point of diversion, not dependent upon this

* Counsellor at law. By request of author.

water for anything but power, the same contributing but a small fraction of the water which ran to these mills.

Upon the practical agreement of the parties, these properties were so remote that no other rule could be employed; we capitalized at a certain rate what we believed to be the going rate of water-power in the vicinity of these mills, and allowed the same as damages for the loss sustained by them in market value.

We treated each piece of property affected separately and employed the evidence relating to that specifically. This involved the problem of the relative value of the water taken to the property affected, and our determination was in no sense, as stated by Mr. Rockwood, "a blind compromise."

In order to pass upon this problem, we first determined the amount of water taken, ascertained the head and fall at the different mills, took into account the wastage of water and the loss of power on the wheel, and made up a table of the loss of water-power at each mill. So far as class four is concerned, as already stated, we capitalized, using a certain rate of interest for that purpose. As to the mills in the third class, we determined as to the value of horse-power at each mill; and, considering the loss of water for other purposes, and then taking into account the market value of the mills, determined upon the evidence how much damage was suffered at each mill. In so doing, we necessarily had to determine the value of water per horse-power at each of these properties. This value was so dependent upon the character of the mill, its location, etc., that we naturally found that it varied at different properties. I know of no rule by which such power can be valued as being the same in every locality, and I think, among men that are acquainted with this subject, there can be no disagreement upon this question. Such valuation, as every practical engineer knows, is dependent upon the case in hand, and I am sure will continue so to the end of the chapter. It must not be overlooked that, while it is easy to determine the amount of power lost, and the going rate of such power in the neighborhood, sold in certain quantities, that result can only enter into the estimation of damages as an element and not a test, and that there are many other things to be taken into account to the end that the damages shall be placed upon a correct basis.

The Worcester case was to me a very interesting one, partic-

ularly in the evidence offered by the hydraulic engineers. They differed in amount, but that depended largely upon the theory upon which they were instructed. These differences in values, unexplained, are oftentimes made the basis of charges against engineers, that they become so intensely partisan as to forget their real opinions. I have listened to a great deal of this evidence, and while I have heard very exaggerated values put upon property, I have almost always discovered that the cause of it was rather due to the different and opposing theories upon which they were acting than to anything else. In valuing, particularly for the purposes of capitalization, the different rates of interest adopted by the experts, running sometimes from three and one-half to six per cent., make a very vivid difference in result. With this, there are many other conditions that enter into these cases that I need not speak of. The serious disadvantage is that sometimes engineers will carry a theory to the extreme, but that is usually upon the direction of counsel. When this is done, the commissioners or valuers are certainly called upon to find a just mean dependent upon the evidence and upon their judgment. This is not what Mr. Rockwood is pleased to call "a blind compromise," but is the best result, in which the calculations, computations, and opinions of the experts play a certain part, as well as the other evidence that is offered in such a case.

Mr. H. de B. Parsons.—This is always an interesting question. As presented in the paper, there appears to be merit on both sides of the Kettle Brook case.

A "horse-power" is the rate at which work is performed, the amount per unit of time. It is therefore taken as a measure. In this sense it can be and is actually rented every day. A horse-power does not exist, and cannot be handled. It has a value, because the power of which it is the standard of measure can be made income-earning, just the same as a corner lot. A corner lot is more valuable than the lot adjoining, although of equal area, because it has greater street frontage, and has, therefore, a greater power of income-earning. This income-earning is the measure of the value, as the value is that sum capitalized which will bring the income at a fair rate of interest.

The value of a horse-power is determined by a detailed calculation of its earning-power. It naturally has no fixed market

rate, and never can. Each power privilege must be treated separately and on its merits.

A large natural source of power, located in an industrial centre, would always command a high value, but the same power situated in the wilds of Africa or of Greenland would probably be unsalable.

The principle upon which the value of water-rights should be determined, according to the writer's opinion, may be briefly expressed as below. No fixed rule can be made which would be applicable to all conditions and situations. The principle may be retained, but modified to suit individual cases.

The value of a water-right consists of two parts, which are closely related to each other.

SCHEDULE.

Value of water rights { (a). Value of water-privilege *per se*. (b). Value of water-power as utilized.

If power be undeveloped, the value is expressed in "a."

If power be partly developed, the value is expressed in "a" and "b."

If power be all developed, the value is expressed in "b."

First—The value of water right per se.

The owner does not own the water, but merely a right to use it. This right has some value, because one might buy the particular land for the privilege of making use of the power. As the privilege thus stands undeveloped, it is not income-earning, but it certainly has a future or speculative value. The value must be modified by considerations of geographical position and the possibility of future use. On this latter point, expert opinion will vary, and perhaps rightly so, as men cannot be expected to look upon futurity from the same view-point. The problem under this last consideration is similar to that of corner lots: one may be on a street with good future prospects for improvement, while the other be not so situated. But then, how valuable are those prospects?

Power can be generated and transmitted long distances, and it does not have to be used at the point of generation. The cost of transmission, however, reduces the value in some ratio proportional to the distance. And likewise the situation may be such that the cost of delivering and shipping goods to and

from the source of power may be so great as to render the water power unworkable at a profit, and so valueless.

Second—The value of the water power as utilized.

The value of a horse-power is determined by calculating the cost of its production, charging interest on the cost of installing the plant, repairs, depreciation, labor, supplies, etc. The difference between the cost of a horse-power produced by a water-wheel and by a steam engine is the saving due to the use of water, and this sum capitalized at a fair rate of interest will represent the value of a horse-power at that particular water-privilege. Expert opinion should be reasonably close on this determination.

The size and character of the steam plant should correspond to the power utilized, and be assumed of a class suitable for that power, and of an economical type.

If the water plant has to make use of a system of transmission in order to bring the power to a place where it must be used, then this transmission should be charged to the water-power plant. In like manner if the water-power plant be situated so that excessive charges have to be paid for delivery of material, both to and from the plant, then these charges should be reduced to a horse-power basis, and be also added.

If the cost of the water horse-power exceed that of steam, then there is no value to the water power as utilized, and the only value that could be attached to it is some value under "a," whereby the power might be made commercially available for some purpose other than that for which it is used.

The difficulty is in determining the flow. This can generally be settled within reasonable limits. Obviously, it is not fair to take the maximum flow, nor yet the minimum. The average flow in many instances is sufficiently accurate, but not always. If the flow be so irregular that a steam plant is necessary to reinforce the water, then that steam plant should form part of the water plant in figuring the cost of a horse-power. The same would be true for a storage reservoir.

As stated before, each case must be taken by itself on its own merits.

The writer has decided views on "expert" testimony, and believes it should not be taken under the rules governing ordi-

nary testimony. In most cases, the attorneys seek to define the line along which the expert testimony shall proceed, and the witness endeavors to carry out his instructions. This frequently leads to a narrowness of opinion as expressed, and to a diversity between witnesses, which in reality may not exist. In the case under discussion, however, the expert witnesses were of an exceptionally high order.

An expert witness should give his opinion as based on his technical training or experience. He should never be interested in the case under discussion, beyond that natural instinct to be on the winning side. He should never testify unless he feels that his client's case be correct. He should never seek to partly conceal his views lest such testimony be adverse to his side of the case, but should always express himself clearly and unequivocally irrespective of the consequences. The expert should be controlled only by his effort to assist in bringing out the facts as he believes them to exist.

A court, a commission, or a referee should always grant an expert witness full liberty to define his views, and not compel him to answer "yes" or "no" to questions asked for the purpose of securing an apparent self-contradiction.

Mr. Alfred H. Raynal.—Not being in the profession of the consulting engineer or of the selling engineer at present, I think I am in a position to judge this paper impartially. My previous experience during a large number of years in the New England cotton-mill trade, in engines, has brought me in contact with a very high grade of men—the treasurers of cotton mills, men who keep very close tab on their expenditures and income, men who know exactly what the value of their horse-power is to them, and in selling engines to these people I have noted more than once that my propositions depended entirely on what that horse-power was worth to them, whether I could sell them a high-speed single-cylinder non-condensing engine, using perhaps 30 pounds of water, or a condensing Corliss engine using 20 pounds, or a multiple-cylinder engine going down as low as 14 pounds. I found that there was a certain price of water-power, but that this price of water-power was different at different mills; and therefore, complimenting Mr. Rockwood on his very interesting paper, I would most heartily second his motion.

Mr. William Kent.—I was called into this case after the death of Mr. Emery and worked very hard on it for a couple of

months, and the result was a great mass of notes and figures and arguments and conversations with fellow experts and with the attorneys, and I think everything that is mentioned here by Mr. Rockwood was gone over, every side of the question that could be thought of was considered. I wrote out arguments on both sides of the question, and considered every possible phase of it. I believe every witness is sworn to tell the whole truth, but no witness is ever allowed to tell the whole truth. It is physically impossible for him to do it, for the simple reason that he is directed by the Court to answer the questions that are asked him and nothing else. He is not told to give a lecture on the whole subject and give his general ideas; but he is asked definite, particular questions, and the Court compels him to answer these questions and no others. So the result is that he gives a portion of the truth, and is all ready to give the whole truth, but before he gets the chance to do it he receives this admonition: "Mr. Witness, that will do," and he is then dismissed after a brief and unimportant cross-examination. In this particular case it seems to me that the question asked of the witnesses for the manufacturers—What is the fair market value of a horse-power?—is a question that had been discussed over and over before, and it had been shown by precedents from time immemorial in Massachusetts and elsewhere that there was such a thing as the market value of a horse-power, and that it was a commodity, and was sold and bought, and had been so considered the whole world over, and there was no court decision to the contrary.

It seems that no witness, as far as I know, on either side, had any success in his attempt to establish Mr. Rockwood's propositions, either that there is no such thing as a horse-power as a commodity, or that the damage is the amount of the coal which would supply it. He says that the witnesses on the side of the defence—that is, for the city, Mr. Rockwood's side—some of them, said something about the coal. "Hence a coal pile large enough to do this, if freely supplied to them, would place them in as favorable a position to carry on the business of manufacturing goods as they ever enjoyed." No witness could make that statement and stand a cross-examination on it—not even Mr. Rockwood. This proposition, to any one who has examined it thoroughly, is absurd. He says further:

"Some said they should also be allowed supplies—waste as

and oil and labor. Still others thought they should, further, be allowed a part of the interest, depreciation, taxes, and repairs on the steam plant; such a part of the whole amount of these items as the lost power bore to the entire power of the engine."

So there are plenty of reasons against his coal-pile theory given by the witnesses on Mr. Rockwood's own side, and there was not so much difference, as he thinks, between the witnesses on one side and the other. If the witnesses on both sides had been brought together in a room as engineers and friends to discuss the whole question, they might have reached a result which would have been very near what the verdict was.

Mr. Rockwood shows very clearly that whenever any witness attempted to establish his proposition, or got anywhere within measurable distance of establishing it, he got into a quagmire. He says:

"It is a fact that Mr. Goulding succeeded in mixing up nearly every one of the city's witnesses by propounding to them the same question." Pretty good evidence that he is a smart attorney, and that these witnesses had good reason to tremble when they attempted to establish Mr. Rockwood's proposition.

The last sentence in the paper is all right:

"Meanwhile the water boards of our cities are acquiring by legislative processes stream after stream now yielding water-power for industrial purposes, and it is of great financial importance to mill owners and water commissioners alike for engineers to have a united, rational opinion as to the true way to estimate the value of a water-power."

That is all correct, and I trust that this committee may do something, although it seems to me it is a matter rather of jurisprudence than of engineering, and that the proper committee would be one to be appointed by the Massachusetts Legislature. But nevertheless I hope our committee will do something, and will help to clear the engineering profession from this disrepute in which it is held by the lawyers, who ought to know better; because the engineers give testimony on both sides of the shield. One tells the way it looks to him, and the other the way it looks to the other, and the true inwardness does not appear from either side. In fact, in the consultation between ourselves and our lawyers, both sides of the shield were looked at, and the true inwardness also. But it is the fault of jurisprudence, not of engineering, that the methods of finding out damages and

settling such cases by law are not to put a witness on the stand and say, "Tell us your whole opinion about this thing," but are for the lawyer to fix his questions so that the expert only answers one side of the question and the other side is left for the opponents to bring out.

Prof. Thurston.—Before Mr. Kent takes his seat I would like to ask him if his experience in this case has led him to any decided opinion regarding the advisability of the Court taking on the expert, and not the counsel on either side, or of allowing the Court, by law, the privilege of employing an expert, or a board of experts in important cases, who shall advise the Court, and, when agreed upon between the counsel of the parties on both sides, act as experts for all in suit. I propounded this question to a chief justice of the State of New York, not long ago, and he, individually, did not apparently approve of the proposition; but it occurs to me that experience on a case of this sort might yield some points of view that would give a man strong convictions. I am interested in getting some evidence on this subject.

Mr. Kent.—I know that it is said generally that, where the witnesses are *ex parte*, each one swears for the side that he is employed by, and that therefore there should be no expert witnesses. Another view is that the expert witness should be *ex parte*, should be employed by each side and present the strongest possible case he can, and then the judge comes in and decides. While the two sides of the shield are presented in that way, the inside is not presented. I think that the method of having a Court expert employed by the Court should be adopted; but I think not as a matter of law, but as a matter of equity between the two parties—that is, by consent of counsel. There should be a third set of experts. That is, there should be the two experts, or two sets of experts, employed by the counsel of each party, and a third expert employed by the Court who should frame the questions for the other experts, and have those questions answered by both sides.

The idea that a Court expert can be substituted for *ex-parte* experts is all wrong, for who is to insure that he has that scope of knowledge, that breadth of judgment, and that freedom from pre-conceptions that he can see all sides of the case? The whole truth is more likely to be brought out by the conflict of the witnesses on opposing sides.

There is something entirely wrong to-day with our present method of engineering jurisprudence, in that the true inwardness is not always brought out; but the two sides are presented, each one partially, not because the experts do not wish to give the truth, but because the expert is prevented by the lawyer from giving the whole knowledge or the whole opinion he has on the subject.

I had occasion recently to take part in an arbitration, at least I was the sole arbitrator in the case. It arose out of the difference between the purchaser of an engine and the seller of an engine. They could not agree. So I had a hearing right at the engine, and each party stated his case in the strongest possible terms, in ordinary language, without any rules of legal procedure at all. Then I said, "I will now suspend this matter, and I will write out a series of questions which I will give to each party, and he is to give me his answers as best he can to the questions which I shall submit in typewritten form. When I get these answers I will send a copy of the answers of each to the opposing party, and then let each bring in a rejoinder. Then I will have the whole state of the case before me in writing, and when I get that far then I will determine what to do next." That was enough. When I got in the two answers and the two rejoinders, I had all the data that were necessary for me to make a final decision. The chief trouble in this Massachusetts case was that the commission did not have to give reasons for its verdict. We don't know what this commission did. I say that whenever a decision is rendered in damage suits in an engineering problem of this kind the judges should be compelled to file their reasons.

Prof. R. H. Thurston.—Possibly both sides in this case may be right fundamentally from the point of view chosen. It often happens that the shield is not only of a different color on the two sides, but entirely different within; the testimony or judgment is honest and correct, so far as it goes, but yet the true inwardness is not perceived by either side.

Here is another method of statement of the case which may possibly aid in securing a reconciliation of apparently conflicting statements of principle and of undoubted fact. This sort of reconciliation of opposite deductions from facts of limited range is often one of the highest duties of the professional engineer when acting as expert in controversies.

(1) The privilege of securing power, useful energy, from a potential water-power is of real value; it is, therefore, in a true sense, property, if the privilege is not, like that of breathing the air, free to all.

(2) Where a water-power is actually developed and in use, the proprietor enjoys a possession of directly measurable quantity and value; it is a property in productive condition and differs from the preceding case, very much as unimproved city lots differ, as property, from those built upon and returning a satisfactory profit to the owner.

(3) The value, in Massachusetts, as now in many if not most States of the Union, is, for the purposes of the courts, and for valuation by the experts in this case, the "market-value" under the ordinary conditions of purchase and sale in a fair average state of the market; not, as to-day, in a state of congestion consequent upon the relief from a recent artificial depression, or in the state of collapse, comatose through the action of such conditions as prevailed, as is remembered well, in 1892.

Every manufacturer in the localities under consideration, and every expert engineer familiar by any considerable experience with the locality and its business conditions, knows what may be fairly taken as the ordinary state of a good market, and what is a fair market value for his own property or his neighbor's.

(4) It may be fairly asserted, and is commonly assumed, that a fair market value is that which represents the capital which would, in average states of the market and during the immediate future, probably earn an equal *net* return on the investment if employed in any other safe and reasonable enterprise. It is that rate which measures the value of capital loaned on long-time securities in the locality in which the proprietor would borrow capital if proposing to use it in his business—say, to-day, in New England, 5 per cent.

(5) The true market value would be approximated at a well-advertised sale, in good ordinary business times, where ample capital is available and seeking a long-time investment. Ordinarily, a sale at auction would only approximate the true value, for some such reasons as make it impossible to secure perfection, ideal perfection, in design or construction; but while the true market price would usually be somewhat above that measured investment value, even with conditions as prescribed, the ap-

proximation might actually be on the other side as a consequence of special conditions, as where bidders forget real values while heated by opposition and competition. But this definition is, perhaps, the best we can give. It gives a substantially correct valuation.

(6) The gain or loss of the proprietor who is deprived of his right to a potential, or an actually developed and utilized, water-power may or may not be the market value. That value is established by the business conditions which affect potential buyers. The value to the man holding it is determined by its value, *to him*, under the particular circumstances of his ownership.

It may be worth the capital represented by an earning power of $50 per annum to the market, to potential buyers of the neighborhood; but it may have special value to him, in consequence of peculiar conditions occurring in his business, such that he would not part with it for the price which would assure him an annuity of $75 or even $100. On the other hand, it might happen that, however high its market value, as measured by the laws of commerce, he is on the point of giving it up entirely in consequence of some change occurring in his methods or plant. If, in this case, he does give it up, and, for example, runs by steam or by a gas-engine, it has no value for him, and its market value for others becomes practically zero, unless indeed the proposing buyer can utilize it without difficulty, and practically as well as if he were the original user. Ordinarily the presence of the original owner and his plant would prevent any one buying the privilege alone, and its market value would thus, for the time, cease.

(7) Thus, if the property is to be appraised at its market value, or if it is to be valued at the actual loss to the proprietor from whom it is taken without his consent, two distinct methods of valuation are applicable.

(8) If it is determined that the market value is to be the basis of settlement, that value is properly determined by the estimates of expert manufacturers or their engineers, when of sufficient experience in such a business, and by their examination of the locality, the existing commercial conditions, and the special circumstances of the place and of the case, so far as they affect the earning power of the fall. It is settled by their conclusions, in settling upon the sum of money which, were they

engaged in business at that place and under such circumstances, they would consider the water-power worth in that business, or, if there be such, in any other use that might prove there and then practicable; basing their comparisons upon *net* earning power.

(9) If simple equity is to be the basis of settlement, the same class of experts should be employed to ascertain what is the actual loss, direct and indirect, of the proprietor through deprivation of his privilege of drawing upon the stream for his power to the extent to which it is actually available.

(10) *A market price*, settled by the market, as in the first of these supposed cases, does not depend upon the value of the property sold to the individual proposing buyer; except that, if the market price exceeds its value to the individual, he does not become the buyer. It is that price at which, being settled for the commodity by general considerations, and without reference to individual and special conditions, it will find ready sale among those classes needing it. The only way to ascertain this value is to study the records of the market as do, to-day, often, dealers in iron, copper, and other products. It is customary in many departments to diagram the course of prices for as long a series of years as records can be found, and then, a smooth curve being drawn through the recorded data, that line is the fair average market price for the period studied. This method may even predict the approximate values of the commodity in future years, where unaffected by any "catastrophic" conditions.

Under these conditions of valuation, the owner may receive more, or he may receive less, than a true equivalent for his lost property or privilege; but he will get what he would have fairly been entitled to expect, had he voluntarily sold out, prescribing such conditions of sale as would permit the buyer to make full use of the water-power. It may be either a loss or a gain to him; but the buyer will have paid a fair figure.

(11) *An equitable compensation* would be that which would leave the despoiled proprietor as well off as before he was thus forcibly deprived of his property, plus a sum, ordinarily slight but possibly quite important, which would measure a fair sharing with him of the advantage gained, in excess of market value or equitable price, as the case may be, by the party in whose behalf the confiscation was legally authorized. For it may be taken as a rule that the forced transfer of property implies the

gain by the receiver of a larger amount than its precise market value. This may be in actual property value under special conditions or, as in most such cases as those here considered, in a more important sanitary gain.

(12) *The market value* is ascertained by considering what is the usual and what is regarded as a fair price in the neighborhood for such a privilege, and what has been the usual consideration where transfers of a similar nature have been effected in the past, as well as what, in the opinion of the appraiser, the property would to-day bring in a satisfactory condition of the market as judged by an unprejudiced and expert onlooker.

(13) *The equitable price* to be paid by the confiscator should be settled by ascertaining what the original owner has done in replacement of his lost power and the difference made to his business, in its dividend-earning capacity, by the change; including costs of change of source of power, of alterations of plant, of delays and annoyances and actual losses thus incurred, and all gains and losses brought into a balance-sheet, and the true balance capitalized at a fair "going rate" for capital, in average conditions of the money market.

(14) These estimates being made by competent appraisers, it *may* be found that the two valuations practically coincide. Should they differ, the figure to be adopted is determined by the specification of the law of the State, as interpreted by its highest courts, if there should be a question of interpretation.

(15) The steps to be taken in the settlement of such questions are:

(*a*) Ascertain or secure a distinct interpretation of the law, and have it understood by both sides and by the referees.

(*b*) Determine whether it is a market price or an equitable figure that is prescribed by the law as the basis of settlement.

(*c*) If a fair *market price* is sought, seek the records of sale of similar properties and privileges, as nearly as may be under the precise conditions of the case in hand. Adjust the mean market price thus ascertained by reference to any circumstances that may make the property under consideration more or less valuable *in the market*—not to the proprietor—and state the result as a fair and reasonable market value. This is a value adjusted to the great market of buyers and sellers as a kind of substantial mean, and not adjusted to the exact worth of the property or privilege to the individual who happens to hold it

and to use it under conditions which necessarily are usually not precisely those of the average user or holder. It is that value at which the average buyer and vendor find that they can do business with mutual gain.

(*d*) If *an equitable valuation* is sought, as between the old and new holders of the property or privilege, proceed to ascertain precisely what is the value to the individual user, present and prospective, and the cost to him, *net*, and as a mean for the immediate future, of the loss and of the compulsory change; these two quantities being quite independent values, and determined in amount by the conditions of the individual case. It is that valuation which, being paid this individual owner, will leave him as well off as before.

Its nature may be seen and its values perhaps best adjudged when it is considered what, in all probability, would be the correct estimate of the gains and losses, incident to the transaction when seen from a proper standpoint some years later. If the compensation is such as will presumably place the original holder of the property in as good a position, financially, ten years or twenty years hence, as he would probably have held had he been left undisturbed, equity is fully satisfied; otherwise not.

The law of some States, as in Massachusetts, I think, settles the primary question, however, by directing assessment at "market value."

These are offered as suggestions, and not at all as positive assertions of fact or principle. But it seemed at least possible that such a syllogistic statement might clarify the case somewhat, and perhaps aid in reaching a correct code in settlement of such disputes. They are definite propositions, at least, which may serve as texts for discussion. Estimates, however, here and elsewhere are usually expressions of judgment, approximate at best, and not matters of scientifically determined fact and conclusion.

No. 849.*

COLORS OF HEATED STEEL CORRESPONDING TO DIFFERENT DEGREES OF TEMPERATURES.

BY MAUNSEL WHITE AND F. W. TAYLOR, BETHLEHEM, PA.
(Members of the Society.)

THERE is, perhaps, nothing more indefinite in the industrial treatment of steel, than the so-called color temperatures, and as they are daily used by thousands of steel workers, it would seem that a few notes on the subject would prove of general interest.

The temperatures corresponding to the colors commonly used to express different heats, as published in various text-books, handbooks, etc., are so widely different as given by different authorities, it is impossible to draw any definite or reliable conclusion. The main trouble seems to have been in the defective apparatus used for determining the higher temperatures. The introduction of the Le Chatelier pyrometer within the last few years, has placed in the hands of the scientific investigator, an instrument of extreme delicacy and accuracy, which has enabled him to determine the temperatures through the whole practical range of influence, and led to the establishment of new melting and freezing points of various metals and salts, which are now accepted as the standard in all scientific investigation. There has not, however, been published any results with the Le Chatelier pyrometer seeking to establish a correspondence of temperatures with color heats.

The first work done in this line, of which we are aware, is that of Dr. H. M. Howe, some eight or nine years ago. His results, however, have not been published, and with his kind permission we are enabled to give them here:

Dull red.....	625° to 550° C.	1,022° to 1,157° Fahr
Full cherry	700°	1,292°
Light red.....	850°	1,562°
Full yellow..... .	950° to 1,000°	1,742° to 1,832°
Light yellow.....	1,050°	1,922°
Very light yellow....	1,100°	2,012°
White.....	1,150°	2,102°

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

The nomenclature used for color heats differs with different operators, but in our investigation we have adopted that which seems more nearly to represent the actual color corresponding to the heat sought to be represented. We have found that different observers have quite a different eye for color, which leads to quite a range of temperatures covering the same color. Further, we have found that the quality or intensity of light in which color heats are observed—that is, a bright sunny day, or cloudy day, or the time of day, such as morning, afternoon, or evening, with their varying light—influence to a greater or less degree the determination of temperatures by eye.

After many tests with the Le Chatelier pyrometer, and different skilled observers working in all kinds of intensity of light, we have adopted the following nomenclature of color scale with the corresponding determined values in degrees Fahr. as best suited to the ordinary conditions met with in the majority of smith shops:

Dark blood red, black red	990°
Dark red, blood red, low red	1,050°
Dark cherry red	1,175°
Medium cherry red	1,250°
Cherry, full red	1,375°
Light cherry, bright cherry, scaling heat,* light red	1,550°
Salmon, orange, free scaling heat	1,650°
Light salmon, light orange	1,725°
Yellow	1,825°
Light yellow	1,975°
White	2,200°

With the advancing knowledge of, and interest in, the heat treatment of steel, the foregoing notes, it is hoped, may prove of some value to those engaged in the handling of steel at various temperatures, and lead to further and wider discussion of the subject, with a view to the better understanding and more accurate knowledge of the correct temperatures. The importance of knowing with close approximation the temperatures used in the treatment of steel cannot be over-estimated, as it holds out the surest promise of success in obtaining desired results.

This demand for more accurate temperatures must eventually lead to the use of accurate pyrometric instruments; but at present

*Heat at which scale forms and adheres, *i. e.*, does not fall away from the piece when allowed to cool in air.

the only available instruments do not lend themselves readily to ordinary uses, and the eye of the operator must be largely depended upon; therefore, the training of the eye, by observing accurately determined temperatures, will prove of much material assistance in the regulation of temperatures which cannot be otherwise controlled.

DISCUSSION.

Mr. William Metcalf.—Cherry red it was pronounced to be ages ago by some person who never saw an orange, and cherry red I suppose it is to be to the end of time, although after the first blush of color, properly enough called dark cherry red, or blood red, and with equal propriety orange red, there is not a trace of red in the heat colors of iron. The colors run through the orange or lemon or yellow tints, as you will, and not through the reds. If we must endure the cherries let us at least be decently near the truth at the other end; notwithstanding the books and the experts, no man ever saw a piece of "white" iron unless it were painted.

Mild steel melted-liquid is only up to cream color, and a heat of Bessemer or of open-hearth steel that is anywhere near white is so badly overheated as to be almost certainly worthless.

Let anyone compare a piece of ordinary white paper with well melted steel, or, better still, compare an ordinary arc light with melted steel, and he will never talk of white hot steel or iron again, if he means to use correct language.

Doubtless gentlemen know what they mean when they say "white" hot steel, but if we want our records to be scientific why not be accurate in language?

White hot would probably be about 4,000 degrees, or as near that as the temperature of a brilliant arc light at its poles.

Prof. Henry M. Howe.—The authors' scheme should, I think, be adopted in place of Pouillet's scheme, hitherto given in many text-books. Indeed, we may well consider whether this Society should not adopt and endorse the new scheme formally; first, because it appears to agree much more closely with common usage than Pouillet's; second, because, while for a large and ever-increasing proportion of cases, it is better to specify the temperature in exact degrees Fahrenheit, neverthess it is often

a great convenience to refer to a range of temperature generically as a "dull red," a "light yellow," etc., without specifying exactly its limits in degrees, just as it is often convenient to speak of "men of medium height" or of "rather tall men" without specifying exactly the exact limits in inches of the group of men to which we refer. The exact and specific reference to temperature has its own particular usefulness, and so has the generic reference. Finally, because it is often desirable, especially in interpreting for legal purposes the meaning of these generic terms, to be able to translate or interpret them at once precisely and authoritatively into the Fahrenheit scale.

To compare easily the authors' data with Pouillet's, I have given them in the following table, together with my own, arranging them so that the entries in any given line represent Pouillet's and my own color names nearest in meaning to the authors'; and I give the differences between Pouillet's temperature and the authors', and also the difference between the authors' and my own.

The greatest difference between the temperatures which the authors assign to a given color name and that which I assign to the nearest corresponding name does not reach 100 degrees. This difference can readily be referred to the personal equation. First, one and the same red-hot object will produce on different eyes different impressions of color; and, secondly, different minds will select different names for one and the same impression of color. Hence it is not to be expected that the temperatures which we have picked out as typical of the different color names should agree accurately. Next, each name really corresponds, not to a single precise degree Fahrenheit, but rather to a range of temperature. Now, even if by a series of coincidents we had agreed exactly as to the limits of each range, we should hardly agree as to the individual degree Fahrenheit in any range which typifies most accurately the name of that range.

But when we come to compare the temperatures which the authors assign to the different color names with Pouillet's, we find very much greater differences, rising to nearly 500 degrees Fahr. This difference is far too great to be referred to the causes just mentioned, and must, I think, be referred to gross errors of color-naming on Pouillet's part.

Of course, when we attempt to displace data which have been

WHITE AND TAYLOR.			POUILLET.*				HOWE.			
Name of Color.	Temperature.		Name of Color.	Temperature.		Excess + (or deficit −) over (or under) White and Taylor.	Name of Color.	Temperature.		Excess + (or deficit −) over (or under) White and Taylor, Degrees F.
	C.	F.		C.	F.			C.	F.	
			(Rouge naissant) Incipient red	525	977		Lowest red visible in the dark.	470	878	
							Lowest red visible in daylight.	475	887	− 90 (under Pouillet)
Dark red, blood red, low red	566	1,050	(Rouge sombre) Dark red	700	1,292	+ 242	Dull red	550 @ 625	1,022 @ 1,157	− 28 @ − 18
Dark cherry red	635	1,175	(Cerise naissant) Incipient cherry red.	800	1,472	+ 297				
Cherry, full red	746	1,375	(Cerise) Cherry red	900	1,652	+ 277	Full cherry	700	1,292	− 83
Light cherry, bright cherry, light red.	843	1,550	(Cerise clair) Clear cherry red	1,000	1,832	+ 282	Light red	850	1,562	+ 12
Orange	899	1,650	(Orangé foncé) Dark orange	1,100	2,012	+ 362				
Light orange	941	1,725	(Orangé clair) Light orange	1,200	2,192	+ 467				
Yellow	996	1,825					Full yellow	950 @ 1,000	1,742 @ 1,832	− 83 @ + 7
Light yellow	1,080	1,975					Light yellow	1,050	1,922	− 53
White	1,205	2,200	(Blanc) White	1,300	2,372	+ 172	White	1,150	2,102	− 98
			(Blanc éclatant) Brilliant white	1,400						
			(Blanc éblouissant) Dazzling white	1,500 @ 1,600						

* Comptes Rendus, III., p. 784, A.D. 1836.

so widely circulated, and replace them with others, we must proceed carefully, especially in view of the high standing of Pouillet, who certainly played a most important part in advancing pyrometry. Barus, in his late classical work on pyrometry, has justly testified to the worth of Pouillet's work.* And, from comparing his melting-point results with those of modern observers, I have been struck with the closeness of their agreement, especially when this is contrasted with the great discrepancy between modern results and those of Pouillet's predecessors.

Thus comparing the results of nine respectable pyrometricians who have since Pouillet determined the melting points of pure gold and pure silver independently, by different methods and under different conditions, I find that the greatest deviation from the mean is only 3 per cent. in case of gold and 2.2 per cent. in case of silver. Compare this modern accuracy with Wedgwood's determination of the melting point of silver, 165 per cent. above the mean of these nine observers, and even with Daniell's melting point of gold, about 33 per cent. above their mean. Yet, strange to say, these old and discredited melting points, and melting points of other metals determined under the same false conditions, though they are no more fit to be set up against modern determinations than are the maps of the Chaldeans to be set up against those of a modern survey, still linger in well-known and reputable books.

But Pouillet's determinations of the melting point of gold and silver (2,192 degrees and 1,832 degrees Fahr. respectively) differ from the mean of these nine later investigators by only 12 per cent. in case of gold and by only 4 per cent. in case of silver. In each case his results are above theirs.

Let the foregoing show that in advising to abandon Pouillet's data I am not ignorant of his worth. But, much as I respect his work, I am convinced that the temperatures which he has assigned to the different tints do not agree with common usage, be it because of his attempt to assign a special tint to each even hundred degrees of the centigrade scale, or because of some peculiarity of his eye, or because the names conventionally assigned in his country at that time to the color impressions produced by different temperatures differ greatly

* Bulletin No. 54, U. S. Geological Survey, page 28, A.D. 1889.

from those now assigned to them here, or for whatever reason. I certainly have found my own color impressions in reasonable agreement with those of other metallurgists; and on examining carefully my own color impressions caused by definitely known temperatures, I cannot force them into agreement with Pouillet's.

A slight modification of the authors' scheme may be desirable. They give a definite degree Fahrenheit corresponding to each color name. While it is well to give such a temperature as the typical or *specific* one to which each name most precisely corresponds, will it not be well to give in addition the whole range of temperature to which each name may more *generically* apply? For instance, while 1,975 degrees is the temperature to which a "light yellow" most specifically applies, shall we not further give the boundaries between "light yellow" and "yellow" on one hand and "white" on the other hand, saying: "light yellow," specifically, 1,975 degrees; generically, 1,900 to 2,050 degrees, etc.?

In reply to the question whether different substances do not give out different color tints for one and the same temperature, I think that there is a general belief that they do, but this is a mistake. My reason of thinking so is the following:

We, of course, see objects only through differences either in the tint or intensity of the light reflected from them. Objects which emit the same tint and intensity of light cannot be distinguished from each other, no matter how different their texture, surface, or shape may be. I have often, in operating on relatively small furnaces, brought the temperature at all parts of the heating chamber to very closely the same point. When this is done all the different objects inside the furnace (firebrick, sand, platinum, iron), after growing fainter and fainter, finally become absolutely invisible. The effect is often very striking. It is not at all due to the eye being dazzled, because this effect can be produced at a low yellow heat, which does not dazzle the eye in the least. It is simply because every object, being at exactly the same temperature, emits the same tint and intensity of light; as all light from without is shut out by the enclosing walls of the furnace, the light which reaches the eye from objects within the furnace comes solely from their incandescence, and as the incandescence of all is exactly the same, they cease to be distinguishable from each other and from the

furnace walls, or, in short, they become invisible. This phenomenon, which I have never seen described by any other observer, seems to me to show very clearly that these different substances must emit exactly the same tint for any one given temperature; for if they emitted different tints they would remain distinguishable from each other, *i.e.*, visible.

Mr. Fred J. Miller.—The late A. A. Simonds, of Dayton, Ohio, followed for many years a business which led him fully to appreciate the importance of uniform and proper heating for tool steel. He devised a pyrometer for that purpose, and in determining how much need there might be for such an instrument he resorted to a curious and rather interesting experiment.

He placed in the hands of fourteen different manufacturing concerns seventy pieces of 1 per cent. carbon steel, each piece being 6½ inches long, 1 inch wide, and ½ inch thick. All of these pieces were from the same lot, and were believed to be, as nearly as possible, alike. All these manufacturing concerns were ones in which a good deal of steel working was necessarily done in the regular course of their work. Among them were three saw manufacturers, three edge-tool manufacturers, three file manufacturers, one agricultural works, one steel manufacturer, one machine shop, one plough works, and one blacksmith. Each of these received five pieces of the steel described, and was asked to carefully harden them. When hardened they were returned to Mr. Simonds, who had them broken in a testing machine. The pieces broke at loads varying from 100 pounds for the lowest up to 1,325 pounds for the highest of those that had been hardened entirely through. The figures for the average strength of each group showed extremes ranging from 265 pounds for pieces hardened by a saw manufacturer up to 1,223 pounds for those hardened by one of the file manufacturers. In other words, the best hardener returned the pieces submitted to him in a condition in which they were about four and a half times as strong as those returned by the poorest hardener. Such figures it is scarcely necessary to say speak for themselves.

In order to get at the differences of temperature required to produce such variations of strength Mr. Simonds himself hardened six similar pieces of steel at heats differing for each successive piece by just 40 degrees Fahr., as determined by his pyrometer. This difference of only 40 degrees in temperature produced very marked differences in the appearance of the

fracture when the pieces were afterward broken at the following remarkable variations in strength:

Piece No. 1 broke at 1,550 pounds.	Piece No. 4 broke at 665 pounds.
" " 2 " 1,010 "	" " 5 " 420 "
" " 3 " 825 "	" " 6 " 350 "

Repeated experiments gave practically the same results, showing that for the best hardening the temperature must be confined within very close limits of variation, and must deviate only very slightly from that which is best for the particular steel under treatment.

While the more intelligent of those who work steel know that it can easily be overheated, there is, I think, generally little idea of how small a variation in heat will make the difference between steel in its best possible condition and steel about ruined, so far as any purpose requiring strength or a durable cutting edge is concerned. It is also not as generally understood as it should be how easy it is for a smith, working under varying conditions within himself, and as regards sunlight, etc., to vary in his heating much more than is at all consistent with uniformly good results.

The selection of the best steel for a given purpose and its best possible treatment in forging and tempering are, I think, of much greater importance in manufacturing operations than the course pursued in many establishments would lead one to infer. In the choice of steel the immediate cent or half-cent per pound is too often allowed to obscure the far greater amounts which might be saved by the use of better steel. But to buy good steel is of comparatively little advantage unless it is to be treated in such a manner as to retain or develop its good qualities. Irregular and uncertain heating is a most fruitful cause of trouble and dissatisfaction with tool steel, and it is probably safe to say that in the majority of cases where a good brand of steel proves to be unsatisfactory it is because, in forging or hardening, the heat has not been what the steel worker thought it was or not such as the steel required. Probably the chief cause of variation of heat, so far as the work of any given man is concerned, is in the fact that the light by which he works comes from the sun and therefore necessarily varies in intensity very greatly, not only as between morning, noon, and evening of the same day, but also as between days bright and days cloudy, summer days and winter days.

In some cases where the manufacture of hardened-steel articles for sale is carried on as a regular business, and where, consequently, the great importance of uniform hardening is recognized as of vital importance, the hardening room is shaded so as to exclude direct sunlight and keep the room in a state of semi-darkness, even when the sun is shining brightly outside. But such a room is yet darker when the sun is low or when the weather is cloudy than it is at other times, and there is probably no way of securing uniform lighting so long as the light comes from the sun.

Some time ago, when inspecting the best hardening room I have ever seen and discussing its equipment and arrangements with the superintendent, a member of this Society, who had designed it, this difficulty of securing uniform lighting was referred to, and the dining saloon of one of the Sound steamers in which I had the night before been a passenger suggested to me a possible remedy. The dining saloon of this steamer is mostly below the water line, and no natural light can enter it. It is lighted at all times by incandescent lamps, which are enclosed in a large tube or tunnel of semi-transparent glass which passes throughout the length of the room near the ceiling. By some such means as this a hardening room could be given a practically uniform illumination. The light could be always of exactly the same intensity regardless of outside conditions, and men working in such a room, when they had once learned to recognize by the eye the proper temperature to secure the best results, could thereafter get this temperature much more certainly than is possible in any room lighted from the sun. I shall hope that some member who is in a position to try this plan will do so and let us know the results.

Prof. Arthur L. Williston.—The experiments of Mr. A. A. Simonds, of Dayton, Ohio, have been referred to once or twice. Yet these little experiments that have been commented on were really but a very small part of an elaborate series which he undertook several years before his death, and which would have been of immense value to us all if they could have been published. Unfortunately, the results were of too much value to him personally in his business to make him willing to have the knowledge that he had gained at great cost public property. I know this about those experiments, however, that he found after extended investigation that it was necessary to determine the tem-

perature at which to harden his steel with great nicety in order to get the best results. This best temperature varied with the different kinds of steel and for different kinds of work, but he found that in order to get results which were uniformly satisfactory to his customers the hardening must be done within a comparatively few degrees of the proper point after taking every precaution to see that the quality of steel and other conditions were kept constant. The temperature was measured by an electric pyrometer of his own design placed in the furnace. When it came to drawing the tempers he was equally particular; it was done in an oil bath, the temperature of which was regulated by mercury thermometers reading up to 600 degrees Fahr. or a trifle above, and great care was taken to see that the temperature of the bath did not vary more than a degree or two from the desired point. I mention this only to show the very great control of temperature which is absolutely necessary both in hardening and drawing tempers in order to get perfectly uniform results.

In the color scale referred to in this paper, there is a temperature interval varying from 75 to perhaps 150 degrees between the successive points on the scale, and those points are so difficult of exact determination that, valuable as the scale may be for many purposes, it necessarily has its limitation as a means of accurately measuring temperature. And where perfectly uniform results in tempered steel are desired, some more accurate means must be employed as the temperature standard than the sensitiveness to the human eye to changes of color.

Mr. Gus. C. Henning.—In this paper the authors give us carefully determined values of temperatures of steel when supposedly showing certain colors. The determinations have undoubtedly been made with great care, and add to our general knowledge of the subject.

However, as no Le Chatelier pyrometer is accurate to such an extent that all readings between 990 and 2,200 degrees Fahr. can be accepted as the values of actual temperatures determined, it would have been well to present in this paper, not only the readings of the instrument, but also the corrections applied thereto. Without this additional information to prove the accuracy of values given, the latter will hardly have great weight in the opinion of careful investigators and authorities.

On the other hand, while the temperatures are given to a sin-

gle degree Fahr. in each case, and not as a range between a maximum and minimun, the colors are mere general terms in vogue in the smith shop (as the paper says), without any attempt at defining or describing them. In most cases the authors give several names to the same color.

These terms are used unhesitatingly, in spite of the statements on page 628, viz.:

"The nomenclature used for color heats differs with different operators, but in our investigation we have adopted that which seems more nearly to represent the actual color corresponding to the heat sought to be represented. We have found that different observers have quite a different eye for color, which leads to quite a range of temperatures covering the same color. Further, we have found that the quality or intensity of light in which color heats are observed—that is, a bright sunny day, or cloudy day, or the time of day, such as morning, afternoon, or evening, with their varying light—influences to a greater or less degree the determination of temperatures by eye."

This statement proves the necessity of accurate definition of the colors under investigation. These colors should have been determined by a comparator and the spectrum, if any attempt were made to determine precise temperatures.

Without this accuracy of definition, the accuracy of statement of temperatures is unwarranted.

Moreover, as the authors state, other investigators using slightly different shades under different conditions may determine other temperatures with equal accuracy and of equal practical value.

Dr. Howe's determinations, which, as a rule, are lower than the results here given, must be considered of equal practical value. Other reputable experimenters and authorities have also given results which were found practically correct.* Why should we now adopt new color temperatures when absolutely no proof is given that the colors examined by the authors were identical with those studied by previous authorities?

Mr. Oberlin Smith.—That question of light is of very much more importance than is usually considered. We all know that if we look at a piece of steel in the light of a forge fire or in

* Pouillet, who was a physicist of great renown, determined temperatures almost similar to those of Howe, except that white heat is given somewhat higher.

bright sunlight it seems perfectly black, and if we lay it in a shadow back of the forge it may appear dull red. Those youngsters of us who used to do "water-annealing" were very particular to get the steel so that the red had just left it in a dark place—not having the slightest idea *how* dark. Then, upon the rare occasions when it happened to be rather soft, we would claim that water-annealing was *the* thing, over all other annealing.

It looks to me as though some sort of a photometer test will perhaps come into use. Speaking of the interesting experiment of sending out the pieces of steel for shop tests, there seems to have been no account taken of what the steel was dipped in, even with the manufacturer's own test. That is another point we are not particular enough about. In a given steel, hardness depends not only upon its own temperature, but upon that of the water or other liquid that it is dipped in, together with the density of the same and the quickness with which it gets hotter. In other words, its heat conductivity, from any cause, seems to really be the determining factor in the case. Of course, when we dip a large piece of steel in a small tub, the water heats so quickly that the metal retains its heat too long to harden properly.

We therefore must consider the kind of steel, its temperature, its size and shape, the size of the bath, its temperature, its composition, whether it is a running stream or a placid pool, and whether the steel is held still or rapidly moved. As any or all of these conditions may vary, as well as the darkness of the room, we surely cannot take mere color as a safe criterion.

Mr. Henning.—I merely wish to call attention to the fact, not that these names are wrong, but that they do not indicate anything definite to us. If the names are retained and we are told what these colors are it will make the figures of the highest value, and that information might be added to the paper. Then, of course, we would have absolutely accurate data of these color temperatures. I am sure the work has been done as well as it can be done and the apparatus is perfect; only I think we are entitled to know which particular colors or heat aspects were examined by the different observers who made these tests. Undoubtedly they are very good, because they were made by as many as the paper says.

Mr. George R. Stetson.—I have an idea that there would be

much difficulty in getting at the matter of colors with any methods at present in the knowledge of the profession. Different steels need different kinds of treatment. The great difficulty about color is that very few men know much about colors. There are very few men who can distinguish between different shades of color. The ladies are more apt in that way. I know of one important railroad where they were putting the conductors through the color test. One lady said, "I guess my husband must go through that," and she got a variety of colors and educated her husband on what color was, and he got through. I think perhaps if you would employ a competent lady in respect to the color that you would get better results. The idea is in this experiment of four or five pieces of sample steel being sent around to four or five different people—I did not understand that the request was made for any object that they were to be hardened for. The saw manufacturer had very much the best conditions to harden for, and his experience was the best for just about the toughest condition of steel, and perhaps that piece of steel went to the mechanic, who was turning a very bad piece of metal about that time and he was getting that steel up to condition to turn that metal. Now, the idea of a color, after once being found what you want, that being established and maintained by the color line, is a very good idea, but you have got to ascertain that color for every manufacturer of steel that you are doing business with. I can remember very well when the American steel would not stand at all the common working heat of the ordinary English steel. You would get good results, but you would have to work with an entirely different condition of color. I think that is common knowledge to any practical mechanic. So far as heating steel with the instruments and getting the proper degrees, it would seem that heating liquids would be the most practical way to get at the proper results. I presume that might be adopted. In some large manufactories handling a great deal of steel that is the process pursued. The steel is heated in liquid, sometimes of different kinds, but one very good preparation is ordinary salt, a proper addition of potash mixed with it. There is where your color comes in. It won't do to have too much potash. Clear salt won't temper at all, no matter how high you heat the steel; the salt adheres, so that the water does not attack. It is necessary to establish the condition of color for each grade of steel, and having established

that condition, if you can get a comparison by a standard color I should think that that would be a very good idea; but I suppose a large per cent. of the steel used in the country is heated in an ordinary blacksmith's fire, and there the comparison with the standard color would be the only possible way. If you heat in a bath it would be possible to put an instrument into the bath and maintain a standard for all temperature. So far as drawing steel is concerned, there is no difficulty in drawing steel up to the condition of an ordinary drill, something of that class, by a thermometer made purposely, running six hundred degrees or something over, and heating in that case in a bath of oil, heating a large quantity. But if you come to a promiscuous condition of color you have got to study the subject from the foundation and find out what your steel is and then establish a color for the heat of that steel. Take 10 men and let them have the different colors of pencils that might represent 6 or 8 or 10 different shades and they would have a wide difference in the decision of just what these colors meant, just exactly as our language is entirely loose when we talk about the color of steel. The man is more at fault than the picture.

Mr. Alfred H. Raynal.—I want to remark that it occurred to me that the condition of the surface is very material in respect to the color of the steel. If I understand right, the color is the consequence of the different conditions of a film on the outer surface. Have any of you gentlemen that have experimented in this direction found that a very highly polished steel would show at the same temperature a different color from one that was not so brightly polished? Any married man who has been sent downtown to match a ribbon must know how little he really knows about colors except by comparison.

Mr. Wm. H. Burleigh.—One difficulty in preparing a chart definitely showing these colors is that of duplicating the color of an incandescent body in pigment viewed by reflected light. The luminosity is a property of the color not present in color by reflected light.

Mr. H. H. Suplee.—I am prepared to offer myself as a horrible example of color blindness. I am a victim of color confusion, which is practically another form of the same thing. I am constanly confusing reds and greens, and other colors of different tints, so that it would be altogether hopeless for me to attempt to determine temperature by color. I have been subjected to the

Holmgren color test several times, and I find that the color confusion is not constant; that it depends a good deal on the general physical condition, on the degree of fatigue. If one has been working hard either with hands or head the sensitiveness to colors, if one is at all weak in that line, is very much dulled, and the perception of range of colors is then much less definite; that is, one does not notice a change nearly so soon in passing from one tint to another as when earlier in the day, or when not so tired. Tests made upon me at different times were by no means identical. Colors which I thought were alike on one day I discriminated between on succeeding days. So I think that others may be affected, even if in a much smaller degree than I am, and that every mechanic ought to be tested very carefully. Judging from my own observations, and I have given the subject careful attention owing to my personal defect, I am inclined to think that color confusion is very much more common than is generally supposed, and for this reason it seems most desirable that some other method than that of color be employed for the estimating of temperatures; it is altogether too much like attempting to determine a constant by a variable.

Mr. Henry Souther.—As a practical illustration of the sensitiveness of the human eye to very high temperatures, I would say that when I was foreman of a Bessemer mill it was found, by the ability of the various ones called upon to do it, that it was possible to detect a variation of temperature of 50 degrees at the melting-point of steel. The determination was made use of by the fact that we scraped cold steel into the vessels after they were turned down, and 100 pounds of cold steel caused a change in the color of the steel that was perfectly evident to very many of us. This figured out, by deducting the calorics taken from the steel by the addition of the cold steel, to be less than 50 degrees Fahr. This, at the melting point of steel, is a very small difference.

In conclusion I would like to say that I am one of the color blind, and that I can tell whether a steel is hot or not; evidently it is not by the color, but by the intensity of the light, if you can call it light.

Mr. George Stetson.—It may be that I have drifted from the color of heat to the color of temper. I suppose there is a certain fixed color to a certain degree of heat. I had reference practically to the working of steel, and I think if we tell our

experiences much more we shall find that we are all color blind.

I would answer the question as regards the surface of steel by saying that I have always considered that the higher I polish the surface the better the condition to take temper. It is attacked more readily by any substance that you might immerse it in. When you come to drawing the temper there is no question about that—you have a mirror-like surface in one case to determine your colors and not in the other. A blacksmith makes the greatest effort to get a clear surface on the tool which he is tempering, and the higher the finish the better the results generally are, both in taking temper and deciding what you have got.

Mr. M. P. Higgins.—There is such evident difficulty in judging high temperatures for tempering steel by observing the colors, that it would seem worth while to investigate all other possible ways and means of determining this temperature independently of human eyesight. I would, therefore, like to mention an interesting and successful means of accurately estimating high temperatures in large kilns and furnaces, temperatures ranging from 2,800 to 3,000 degrees Fahr.

It is well known that clays of carefully graded different mixtures melt or show signs of melting at pretty definite temperatures. Small clay cones thus graded and numbered are placed in the furnace, where they are accessible, and a constant indication of temperatures is shown, and a record is also preserved by the condition of the row of clay cones thus used. It seems to me that possibly bits of similar clays could be made to adhere to steel while being heated, and show the proper temperature of the steel to be tempered.

*Messrs. Maunsel White and F. W. Taylor.**—The suggestion of Professor Howe to give the ranges of temperature covering the different heat colors was thought of in the writing of the paper, but it was finally concluded that as the given temperatures were the average of a number of determinations made by different observers seeking to establish by the judgment of the eye the temperature in degrees Fahrenheit of the different conventional colors, it would be best to give the results obtained to the nearest 25 degrees. It is well known that with a rising or falling

* Authors' closure, under the Rules.

temperature the colors blend so gradually, one into the other, it is extremely difficult to establish the exact point in passing from one to the other; thus in passing from light salmon to yellow, the yellow is that point at which the last trace of red disappears; this point was found to correspond approximately to 1,825 degrees, which was selected as the temperature corresponding to this color. The range in which the yellow may be said to predominate reaches to 1,975 degrees, which was termed light yellow, as after this the white becomes predominant, increasing until the eye becomes dazzled or blinded at about 2,200 degrees, commonly called a white heat. It was from this view that only one temperature was selected as representative of each color, so that it may be taken that the range extends about 25 degrees on either side of the given temperature; when going beyond this in range, or approaching the middle line, as it were, it becomes difficult to decide upon naming the color, unless we should resort to the expedient of saying a very light salmon or a dull yellow, a very light cherry or a dull salmon, etc., which is a refinement that would imply the eye was capable of judging color temperatures closer than our experiments proved to be the case.

Thus it will be seen that our results as claimed are only an approximation, but as they were obtained by men trained in the practical heating of steel, it was thought they might be of interest, and possibly a help, to other workers in this field. Also, as they seemed a nearer approximation to the truth than any previously published results, it was thought advisable to establish or disprove them by general discussion before the Society.

A most excellent plan, which has been adopted in several works, is to abolish the use of color terms altogether and use only degrees. Where records of hardening and annealing temperatures of daily work are kept, as they should be, this is the most intelligible method.

It requires but a short training with known temperatures in order to have the operator judge in terms of degrees instead of color, with the proved result that the work performed by different operators is of a much more uniform character.

Nothing would be more desirable, as pointed out by Mr. Stetson, than the use of liquid baths, which can be maintained at desired temperatures for the heating of steel that is to be submitted to treatment. Where this is not admissible, the sugges-

tion of Mr. Miller, that artificial light which can be controlled should alone be used, has been proved to be a most excellent plan to obtain uniform results.

It may be of interest to give a brief description of the method of setting up so delicate a piece of apparatus as a Le Chatelier pyrometer in a blacksmith shop equipped with steam hammers. A stout, heavy box, 15 inches wide by 2 feet deep and 6 feet long, with doors at each end, and on the side near each end, was constructed, and swung by means of two ropes at a convenient height for taking observations. The method of swinging was four posts framed together so that the box could swing freely between them; a cross-piece on top supported the ropes, and the box was held laterally by rubber bands at each lower corner stretching to the corresponding post. With this arrangement it was found that the delicate galvanometer mirror was unaffected by the jarring of the heaviest hammer, so that once set it remained in good working order several months, requiring only slight adjustments now and then. To the painstaking care of Mr. David C. Fenner, of Yale Scientific School, '96, and also Boston School of Technology, '98, who operated the pyrometer throughout our experiments, much credit is due for the results obtained.

No. 850.*

EDUCATION OF MACHINISTS, FOREMEN, AND MECHANICAL ENGINEERS.

BY M. P. HIGGINS, WORCESTER, MASS.

(Member of the Society.)

THE central object of this paper is to outline a special school for the training of boys to fill the successive grades of mechanics from machinists to engineers, and which shall be adapted to train each boy for each successive grade until his particular career is determined by natural selection and he goes out fitted for that career.

Demand for Trained Mechanics.

While it must be admitted that during the past twenty-five years most gratifying progress has been made in American mechanical engineering and in the education of mechanical engineers, yet it is evident to the managers of our mechanical establishments that there is a great lack of competent mechanics below the grade of the mechanical engineer to take the increasing demands and responsibility of the work and properly carry it out.

The standard of the work of the *machinist* has rapidly moved forward in refinements and complications. He is called upon to read and understand intricate drawings, and to make quickly and with certainty very exact measurements and computations in the shop. He must deal with tempered steel for almost numberless uses and for the severest requirements. Hardened steel

---

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

parts must be fitted to an extent and with a precision never thought of twenty-five years ago. This practice of machine construction will be introduced to an unlimited extent in the future, necessarily making many changes in methods, as, for example, the substitution of grinding for filing, which will secure so much better results. This introduces the modern machinist to a field of unlimited possibility requiring most exact knowledge of new and constantly changing methods; and the experience of all employers testifies to the difficulty, if not the impossibility, of securing the requisite knowledge and skill in the machinists of to-day.

If the position of machinist is a hard one to fill, what is to be said of that of *foreman?* At a recent meeting of managers it was stated that 200 young men suitable for foremen for foundries could be placed at once. Nothing is more difficult than to find men capable of filling such positions. Indeed, I have expressed the opinion, and I believe it will be confirmed by others, that the most difficult position to fill when a machine business is to be organized is that of shop foreman. The positions of president, treasurer, mechanical engineer, salesman, etc., need not wait a day for applicants, but the man who is fitted to manage the practical details of a machine shop successfully is a rare man, and there is no scientific or professional man whose services are in surer demand than his.

Is it not wise, economical shop management which is giving us the leading position in the machine markets at home and abroad? This is what we expect the good foreman to exhibit. The ability to produce a very fine and exact piece of work in a machine shop, regardless of time or method, will not insure success, but, on the other hand, will be most apt to induce failure. It is the shop which can build the best machinery at a less cost than others which is sure to be successful; and to secure this the management must depend upon no man more than the shop foreman. He must ascertain all possible legitimate ways and means for reducing shop costs, stopping leaks and losses, without reducing the manliness of the men and the standard of the work. How many men of this kind do we get, and what opportunity is there to-day for training for such positions?

With this great and growing demand of the profession, and with the splendid opportunities open to young men who will fit themselves to be mechanics, and who in turn are demanding of

the profession the chance to fit themselves, the question is forced to our attention: How are these needs being met?

What are Our Common Schools Doing?

Let us see what our common schools and other schools secondary to technical schools and colleges are doing for the education of those boys from which our mechanics are to come. From the educational reports of 1897-8 it appears that, taking the first grades of the schools as a basis, 80 per cent. of the pupils drop out before they reach the high school, and nearly 97.5 per cent. before graduation from the high-school. It is probable that the greater percentage of those who have left school have left it to enter some occupation leading directly to self-support. It seems to be a fact that the average high school graduate, with all the knowledge which he has acquired during ten years of continuous schooling, is not able to earn his living as the result of anything he has learned in school. Therefore he must leave school to learn a trade or take up some occupation as best he may, without the help of further systematic education, which at this period of his life he so much needs. The statistics of the Commissioner of Education indicate that the enormously large percentage of pupils who leave school do so at the age of ten or twelve years, after only about five years or less of schooling.

From the report of the Commissioner of Education for 1896-1897 we find there were 16,255,093 pupils enrolled in the schools, and from the recent paper read before this Society by Edward A. Darling it appears that the colleges and universities of the United States carry on their rolls only 165,000 students, showing that only 1 in about 100 can have the benefit of a higher education. It is believed that a large proportion of the boys who leave school so soon would be induced to continue the school period several years longer, if the additional three or four years of training would impart skill and practical knowledge, so that the ability to earn good wages immediately upon leaving school would be assured, say, at from sixteen to twenty years of age.

Importance of Getting About Life's Work Early.

It is quite generally considered the wisest policy to advise young men to lay patiently a broad foundation in school and to

be content if the life work is fairly entered upon at from twenty-five to thirty-five years of age. But there is a gradual change of opinion taking place among many educators, and they are coming to believe that the most receptive period is under twenty years of age. Therefore, aside from the necessity under which a poor boy labors, who has his way to make in the world as a workman, he should early be induced to look forward with a fixed plan and purpose to his life work, and there should be given him, in some suitable school, a fundamental training which should fit him for his occupation. On the other hand, this must not limit him, as it should lead directly through the successive grades toward the highest professional work of that industry which he chooses.

Failure of the Technical Schools to Reach This Class.

Never was there a national movement more timely or more successful in its introduction than the movement looking toward the establishment of technical schools thirty-five years ago in this country, supplemented as it was by the educational land grant act in 1862. We naturally expected at that time that this movement would meet not only the higher education of engineers, but the needs of mechanics, which this paper emphasizes. Perhaps, however, it was too much to expect that these schools, under the management of professional educators, the most able and suitable that could be selected at that time, could have accomplished so much or covered more ground than they have. It is most natural that each technical school management should be greatly influenced by the college education and academic professionalism of the men who conduct it, to whom were entrusted the relations of academic and practical departments and those of theory and practice. This has resulted in a tendency to produce scientists and not mechanics.

It is not the policy and intention of engineering schools to put sufficient time and stress on shopwork to allow the student to attain thorough practical skill. He very readily receives the impression that an engineer need not work with his own hands, though he admits that he should know how the work should be done by others. To be a thorough mechanic, which he ought to be before he can be a well-trained mechanical engineer, he must be able to do the work, and this the present technical school does not teach thoroughly.

The gulf between the work of the schools and the shops has sometimes been called a difference between theory and practice; but the real variance in educational attempts is between *men*, between the mechanic and the schoolman, between the machinist and the engineer. Brave attempts have been made to bring the two together, but with partial success only. In one of our most prominent and practical engineering schools a professor had designed a commutator which required sections cut from a metal ring. The professor ordered two rings, so that a piece from the second could be used to make up for the loss in cutting up the first. The machinist said, "Let me make one ring only, somewhat larger than you want, cut it up, and then turn it to the exact size, and thus save the cost of the second ring." "No," answered the professor; "I am doing the engineering, I want you to do the work." I state this actual occurrence, as one of many illustrations which might be given, to show that the two have not yet joined work even in the technical schools. It is not always an easy matter to secure this necessary union, and even where it seems to be attained it is not always complete. It can be secured by having both vital parts in one and the same man. And it is exactly this union that the proposed system for training mechanics is designed to secure.

The very surprising fact that the total number of students in technical colleges in this country is at present on the decrease may suggest that some changes in the engineering courses would better meet the needs of a larger class.

This unexpected falling off in the number of engineering students is greater than can be readily accounted for in these prosperous times, amounting to 15 per cent. from 1894 to 1897. These facts were first shown by Dr. Wardsworth, president of the Michigan College of Mines, and since verified by Mr. William Barclay Parsons, Trustee of Columbia University.

Raising of Standards of Admission.

I would also mention that with the tendency toward the abstract and scientific which has been referred to, has come the raising of standards for admission from year to year, so that the technical school has become more nearly on a par with the college than it was when it started, and this puts the school beyond the reach of boys who are to make workmen and also beyond the reach of many who would make engineers.

Prof. R. H. Thurston, in a thorough treatise on this subject, says:

"In the opinion of many of the ablest and most authoritative members of the profession, the process of raising entrance requirements has already gone too far, and the result of carrying the process further, for purely sentimental reasons which do not appeal to the people who desire to send their sons to such schools, will be seriously to cripple institutions of this kind in the work of aiding the industrial classes."

Thus, whatever the advantages of the technical school and college, which I would not for a moment belittle or decry, they do not meet the needs for which they were founded, but leave the uncovered field as large as ever.

Another Unfortunate Result of the Technical School—the Amount of Discarded Material.

As a result of the technical schools overlooking the needs of the large body of mechanics and devoting themselves to the production of scientific professionalists, they produce an enormous amount of discarded material, men who are neither fit for workmen nor engineers, men who are not *at the start* fit to become successful engineers.

In a class of one hundred in an engineering college, if only five make engineers such as the course is aimed to produce, the ninety-five others have not, in all probability, received a course of training well fitted for their special needs and capacities. Further than this, the large portion of the class who are, to some extent, failures are also frequently disappointed men.

There are many reasons why the young man who enters an engineering school is allowed to get false ideas regarding his future. He understands that there is a lively demand in the active world for technically trained young men. He likes the idea of being an "engineer," and he knows that all the leading technical schools have high-grade engineering courses, the requirements are up to the colleges, and he expects when he graduates he will be able to engage in engineering work. When he finds that he either cannot do engineering work at all, or that there are ten engineer graduates to one position of that particular kind, and that every year the demand for professional engineers grows less and the graduates more numerous,

he turns his attention reluctantly to a lower grade of work and is never quite satisfied or happy in it. He feels that he was born and educated for something better. But was he? No. He only thought he was. His failure would be no fault of the school, however, if he had not been, in a sense, educated away from the work that he is obliged to undertake. These "culls" from an engineering class are not first-class material for workmen in any department below the engineer. Such a man is a disappointment to himself and to his employer. And though we may be able to show that every graduate in a class has been greatly benefited and developed during the course of study, yet that is not a sufficient reason for a course fitted only to the very few and which allows the large majority to come to their disappointment through the general understanding that, if they were graduated, they would be engineers *because* they were graduates.

Consider, also, what a fearfully expensive system this is, with its large percentage of failures or partial failures, to educate the few, of which there is already a larger number than can secure positions as professional engineers.

Over-supply of Polytechnic Engineers.

We must remember that mechanical progress is very dependent upon the capitalist. The proprietor who stands behind the work is more and more inclined to trust his engineering to his own men who have grown up in the works after having received a technical education, or by devotion to study picked up science enough to get on with considerable success. The proprietor is not inclined to put his work into the hands of a professional engineer who works on the same problem for other clients, and he is less and less inclined to employ special engineers. When this is done at all, one engineer is employed by several concerns, and his time divided up among them.

This lessened demand for polytechnic graduates was recognized several years ago in Europe, and some slight attempts were made to remedy the evil. As early as 1885 the British commissioners found in Germany an excess over the demand, of 1,000 well-trained polytechnic graduates, and they were informed that the manager of a large engineering works had been so importuned by these young men for employment that he

put a notice in his window, "No polytechnic student need apply." The Baron von Eybesfeld, Austrian Minister of Instruction, stated that the most serious problem in education in that country is to reduce the number of theoretical engineers (who, after their long course of study, find themselves not wanted) and to increase the number of men in whose training theory and practice had been so combined that they could meet the great demand for those who can put theory and practice together. This statement, taken from a report of Technical Instruction in Europe, by the late C. O. Thompson, formerly president of the Rose Polytechnic Institute, and published by the United States Bureau of Education, is followed by another statement which shows that the tendency of the technical schools toward a par with the college, referred to above, was fully recognized and admitted at that time. This statement says: "There is a constant and apparently irresistible tendency in all the lower schools to pass up into the higher by imperceptible advances. For example, at Chemnitz what used to be the Gewerbeschule has ranked since 1879 as a polytechnic school. But so true is it that a school of higher education never loses or departs from the cast it receives in the first ten years of its existence, that the old polytechnics, modelled largely after the Ecole Polytechnique of Paris, have so steadily held to the theoretical training of engineers that the times have swept past them. The efforts now making in Austria to remedy this evil are more to the point than any others in Europe, but they are directed towards the artisan rather than the engineer."

Tendency of Technical Schools.

As a single instance from many that might be cited illustrating the tendency of technical schools in America as well as in Europe to drift more and more out of the reach of the boy who wishes to educate himself as a mechanic, I refer to the history of the Worcester Polytechnic Institute. In 1884 the full course for a mechanical engineer was 3½ years. In 1896 it was 4 years. In 1884 the shop practice for the 3½ years' course was 2,376 hours. In 1896, even with the 4 years' course, the shop practice was only 1,709 hours, a reduction of over 28 per cent., and an increase of time and consequent expense to the student of 14 per cent. In 1884 a year's school work consisted of 42 weeks. In 1896 there were only 36 weeks, a loss of time of 14 per cent.

The productive activity of the school shops has been reduced from $109,027.78 in 1896 to only $20,801.82 in 1898.

Since 1889 the tuition has been raised from $100 to $150, an increase of 50 per cent. In 1873 this institution was able to advertise that the total expenses of a member of the school, including tuition, utensils, and board, need not exceed $380 per year. The present advertised estimate is $450 per year, an increase of over 19 per cent.

Scientists in Engineering.

Though I believe that the education of practical mechanical engineers should begin at the bottom and lead through the various grades of work and attainment between and including that of working mechanic to engineer, I recognize a high realm of engineering which may be reached and occupied by a few who do not reach it through the shops. This is a realm of pure science in engineering held by men whose whole duty and profession it is to deal with theory alone. There are but few born to enter it. Its occupants may be called not engineers, but scientists in engineering. They deal with pure, unapplied science. They have to do with abstract truths. Their work is original research. They discover new laws and make new formulas. They have nothing to do with mechanical difficulties. They have nothing to do with machines, processes, or costs. This highest work is distinctly apart from all the great working forces of manufacturing and mechanical industry.

This line of work need not be entered upon with any expectation of money-making, or that it will have much to do with practical, concrete engineering, or with the live industrial problems of the day, which determine whether a nation is to lead or follow in its industries. This scientist may make discoveries which no engineer or worker is likely to make, and may render great aid to progress by solving difficult problems. Without him the highest success is not attainable in the industrial field. But whether the approach to this exalted and extremely limited realm be by the Gate of Knowledge for knowledge's sake, along what may be termed the "air line," or through the shop by one unbroken steep upward grade, its existence should serve as an inspiration and not a cause of envy and disappointment to those whom nature has decreed shall be workmen.

Proposed Solution of the Problem.

The proposed solution of the problem lies in the answer to the question: "How can we give our boys a chance to learn a *trade* without being deprived of a good common-school education and at the same time secure a foundation upon which to build a higher education if capacity and circumstances permit?"

The HALF-TIME SCHOOL, established upon the plan outlined below, will, it is believed, answer this question and solve the problem.

This school is aimed to fit each boy for the successive grades of mechanics from the machinist up, so that at any time he will be fitted to take up his work outside as a well-trained mechanic in the grade which he has completed, and be prepared to enter the training of the next grade. In other words, the object of the school is to produce *many* well-trained and educated machinists, and from these machinists *some* foremen, from the foremen a *few* superintendents, and finally an *occasional* engineer. The character of the individual material in ability and natural aptitude determines the grade of the product of the school, whether workman, foreman, superintendent, or engineer. The plan will be understood by a brief statement of its prominent features, which will be discussed more at length below.

Chief Features of the Half-time School.

First—A school which shall include a first-class commercially successful and productive machine shop, which is a department coördinate in importance, influence, and educational value with the academic department.

Second—A school in which the pupils are to have instruction and practice in this shop during half the working hours in five days of each week for a period of four years.

Third—Instruction in the public schools during a portion of the other half of the time, equivalent to a high-school course, restricted, abridged, and improved to meet the needs of these pupils.

Fourth—Special care and method of selection of pupils who have finished the grammar-school course and who have special aptness for mechanical work.

Fifth—Management under a corporation whose trustees shall be practical business men.

Before proceeding to a discussion of these features it seems well to say a word upon the principle already briefly stated, which lies at the foundation of this school—namely, the education of one period leading to the next, so that there need be no break or limit until the most complete education of the engineer is finished.

Education Complete at Each Stage.

The main thing which should determine the point where schooling had better be stopped and the real life work begun is the natural endowment of the pupil, so that whenever he stops he has received the best possible course of schooling and training for his particular career, whether it be as machinist, draughtsman, foreman, or manager. And if he has aspirations and natural ability for some position higher, not within the scope of the Half-time School, this course may lead to the technical school. Thus he has no back steps to take, nothing to unlearn, and nothing which he might better have left out. He is not handicapped by lack of preparation to enter the technical school. When he enters the Half-time School he need not give up his aspirations for this higher education, as is the case to-day if he leaves the public school to learn a trade; he has not burned his bridges behind him, but all that he has attained in the Half-time School is the best possible understructure for his higher work, even if he becomes an engineer and undertakes the most responsible engineering works devolving upon mankind. If he is not adequate to undertake such work, it should not be the fault of his school training, but due to the limit of his natural capacity. "Many are called, but few are chosen." We need not grieve at the very few chosen, because but few are required. But few professional engineers can be employed, provided the great body of working mechanics are effectively educated to think clearly, keenly, and quickly. To produce such mechanics is the first object of the Half-time School.

This school begins with the education of the masses as machinists, and then by natural selection promotes to the grades above. The selection and elimination begin at the bottom and proceed upward, rather than, as is now the case with the technical school, beginning at the top and proceeding downward, dropping a large number because they are failures. In the Half-time School, if the boy's natural capacity or the lack of demand fails to take him into the position of engineer, yet he is a suc-

cess as a working mechanic in one of the grades below, and when a boy drops out for any cause, he drops on his feet.

We may hope for much from a thousand educated, thinking, expert American machinists who have the skill, education, and an exact knowledge of the shops. Is not the production of one hundred well-educated workmen a more certain undertaking than the production of one genius? There is certainly no impassable gulf between the ideal engineer and the great body of workmen. If there were, there would necessarily be one school for engineers and a different one for workmen, another for laborers, another for foremen, another for superintendents, another for managers, etc. In the Half-time School all grades may go on together as far as possible.

The real engineer, in consequence of superior natural fitness, carrying capacity for knowledge and practical experience, and cultivated mental faculties, is a superior man to his fellows. His superiority over and above the mechanic, mechanician, or machinist, I insist, however, is a difference of degree and not a difference of kind. All should begin in the same school. The engineer is superior because he takes more, and he takes more because he has the capacity to carry more. Therefore, he cannot afford to be minus any good thing which the man below him possesses; he can afford to have all the specific shop knowledge and practical experience of the workman below him.

The Alpine explorer does not approach the highest peaks from the clouds, but he walks from the foot-hills with his fellows, some of whom never go above the pastures, others never above the slippery glaciers; but he that is fittest keeps step with each and every one so far as each can follow. The hero takes every step that the plodder takes; the only difference being that each step of the better man is surer and bolder, and all along through the simple things a promise of higher things is evident. Every step the hero makes is an inspiration to his comrades, and sure progress to himself. But finally he goes onward and upward, more and more alone. Something of this sort of superiority, I believe, may result from a proper natural training for mechanics, where each boy is inspired by the progress he has made, and consequently feels more and more intensely fixed upon taking the next step upward.

In the present school system the young man may look forward to some higher position he vaguely hopes for, but it is fre-

quently late in life, if ever, that he gets the better help which comes from looking backward over daily achievements (such as I believe a Half-time School with large shop opportunities can give) all along the way from his humblest experiences. Not only when the pupil leaves school he steps upon a level of work for which his schooling up to this point has fitted him in the best manner, but, furthermore, he has been fitted in the best manner to take the next higher work in school at once, or after a year or two of shop work for the sake of earning money, thus enabling him to take a higher course in an engineering school.

Chief Features More in Detail.

To consider more at length the five prominent features of the Half-time School which have been briefly stated, let us consider under the first statement, concerning a commercially productive school shop,

What Should a School Shop Be?

The shops may be designed and equipped upon the same general lines and the same principles which govern the construction and equipment of ordinary shops, whose sole object is to succeed in competition with the best managed shops in the land, engaged in the production of first-class machinery, independent of the school element, which is in this case, however, the sole object and motive.

The building should be a first-class one, ample and convenient, including, as well as a machine shop, a pattern and wood-working room, a small blacksmith shop, plain office, and a draughting-room. Before the shop is located, built, and equipped, it would be well to decide what line of machine work is to be produced and put upon the market, whether machine tools, agricultural implements, pumps, or some other class of machinery. Whatever it is decided shall be manufactured should have in it a large variety of practice requiring the use of a large number of tools.

Several different grades of work may, with advantage, be carried on in this well-equipped shop. Having decided what shall be manufactured, the equipment should then be as complete and suitable as possible. The fact that it is to be a school shop makes it desirable to depart from the usual practice of having lathes and other machine tools all of one make. In this case

the advantage to the students, when they become acquainted with the various styles produced by the different makers, is greater than the disadvantage of non-uniformity. It is not necessary to have the most expensive tools and machinery, but everything must be effective and up to date. The organization and management of the school shop may be almost the same as if the element of instruction was entirely left out. The capacity of the shops should be such that, if desirable, at any time, one-third or one-half as many hired men may be employed as the total number of students.

The Internal Conduct of the Shop.

If a school starts with, say, one hundred pupils, only fifty would be in the shop at the same time, and an equal number would always be in the shop throughout all the business hours of the week, except Monday forenoon and Saturday afternoon, and these two half days would generally be occupied by some students working to make up lost time, or working for pay, by special arrangement with each pupil, so that the uniformity of the working force is not less reliable than in other shops. If at any time Monday forenoon or Saturday afternoon the shop was without students, the work and business of the shop would be carried on by the employed men. The employed men would consist of from ten to fifty expert machinists, besides a blacksmith, a steam engineer, a pattern maker, a draughtsman, two foremen, a bookkeeper, and a general manager or superintendent. The foremen are especially charged with the direction and instruction of the boys, but under the order and direction of the foreman any mechanic acts as an instructor of the apprentices learning the trade.

All employed mechanics are selected with special regard to their skill, and to their fitness to aid and instruct the learners in doing all kinds of shop work by the best, most effective, and economical methods, such as will make a shop commercially successful.

Until one has had experience with a large class of earnest students in a real machine shop, intimately associated with a large number of superior expert mechanics, it is impossible to believe how quickly the students will become competent to do good and reliable work, and how much information and practical

experience they will absorb, not wholly or largely by verbal instruction, but by simple observation.

Thus, it is not only desirable but necessary to have shops wherein a large quantity and variety of machine work is going on in the presence of the students and under their hands and assistance.

Importance of Commercial Shop.

Nothing is more fundamentally important than to do away with all fear and doubt about the desirability and practicability of having a real productive commercial shop in which to train young men in the skill and judgment necessary for practical, efficient work in machine building, machine operations, and mechanical engineering.

Judging from general observation upon this subject, I believe there is no difference of opinion existing among either educators or practical men regarding the *desirability* of having real shop practice; but regarding the *feasibility* of giving such real practice in a commercial school shop there is general doubt. I wish to say that the doubt is without foundation, and that nearly all the grounds for objecting to the introduction of real productive shops as a part of technical and engineering training are imaginary.

Alleged Objections to Real Productive School Shops.

The objections to the commercial shop as a part of the school came about in a most natural manner. The organization and administration of engineering schools have necessarily been in the hands of the schoolmen and teachers—men educated in literary colleges—who have established a reputation as educators, not as engineers or business men.

When American mechanical engineering schools began to be established, such men were the only men deemed competent to assume such responsibility. Thus the novel undertaking of establishing machine shops as a department in the technical school was not unnaturally considered hazardous by the men intrusted with the great and new enterprise. This resulted in setting up what is known as the *instruction shops*, as distinguished from the *construction shops*. Of course the sole object, in either case, was *instruction*, and this was accomplished in the former plan by exercises which produced something neither intrinsically good

nor useful. In a few instances it was thought that a good way to teach construction in the school shop was to introduce something both good and useful, and thus give the young engineer an opportunity to get real experience and learn as much as possible how to do real work himself. But the schoolman saw great difficulties in producing machinery for the market, and naturally did not care to assume the responsibility of having a real machine shop to manage himself; neither did he care to delegate such responsibility to a competent manager, so that a real machine shop should stand beside the school as a department coördinate with it in usefulness and value, as a means of instruction.

What would the heads of the most progressive professions think if it should be urged that it would be just as well for young surgeons to play at hospital practice instead of performing real surgical operations, getting over real difficulties, and saving the lives of patients? If a young man is not practically trained in the anatomy of the machine shop and cannot note the weaknesses and meet the emergencies of it, and if he has not the skill to conduct the case competently himself, the enterprise will not grow stronger, but weaker, and may die like the patient who lacks the competent care and skill of the doctor.

We are aiming in the proposed school, and it is the professed aim of the technical schools and colleges, to aid young men to conduct mechanical and industrial enterprises successfully; and no matter how profound the knowledge or how scientific the basis beneath the industry, the enterprise is a failure if it cannot be conducted practically and made self-sustaining and dividend-paying.

The Real Shop and the Professors of Engineering should be a Mutual Benefit to Each Other.

I believe that professors, instructors, and mechanical engineers of our engineering colleges cannot keep up with practical work unless a commercial shop is maintained, and the only way that such a shop can be maintained is by producing the best modern work by the latest and best methods, and by subjecting the products of the shops to the impartial and excellent test of the open market.

I believe that in the engineering colleges it is only by such real, commercial, productive shops that the professors who de-

vote their attention to teaching the science of engineering and machine design can hope to keep the science up to the art in the shops. Hence I regard the commercial shops as a great help to the professors; but the amount that the shops may be aided by the professors is also great, and the complete union referred to is necessary to insure success.

A School Shop Cannot be too Practical.

It has heretofore been feared that a technical school might become a shop with a school attached. This gives rise to the danger of a shop becoming weak and impractical.

There is a strong argument for school shops which shall be much more intensely practical than any which have ever been established or advocated. School shops should be object-lessons, in every sense, as to the conduct of a first-class manufacturing establishment. They should, to an extent as complete as possible, illustrate good and economical shop methods such as must inevitably lead to a successful business.

It would be a very narrow claim for the school shop to say that its only desire is to teach the names of the various machine tools and their uses, how things are operated, how a chip may be taken off, and have nothing further to do with preparing a young man to organize a machine business, and produce machinery which in quality and design would take the lead in the markets of the world, and produced by such advanced methods and economical management that no competitor in the world can take the market away from him.

The ability of our graduates of engineering colleges to be able to talk intelligently about machinery, and to run the machine, or even to be able to produce a very fine and exact piece of work regardless of time or best method, will not give success. They must build the best machinery at less cost than others.

The importance of securing wise, economical shop management, particularly of the kind which manufacturers look in vain for foremen to possess, has already been emphasized in the introduction to this paper, and the lack of any systematic, practical training in such an important element as economy in a successful mechanic has already been referred to.

Costs.

It seems to me that this important kind of experience just referred to can best be obtained in a school shop. It is too expensive when obtained in business life, and is the most costly subject of any to the manager. I would give a distinctive place to a Department of Costs in the proposed school, and emphasize the importance of it.

I have thought that such a department may be subsidized by external aid, so that the expense of the investigation, determination, and comparison of costs need not be chargeable to the general expense account of the school shop, but might be borne by manufacturers, to whom reports on such a subject would be of great value.

Other departments in connection with the school shop, which it is not necessary now to consider in detail, I would have conducted along equally practical lines.

Proper Standards for School Shops.

It is of great importance that a high standard be at once established and maintained. There is commonly considerable danger of attempting to accommodate the shop standard and requirements to the inexperiences of the pupil. It is, however, never necessary to lower the standard because the work is to be done by boys. It is surprising how students will readily approach a high standard. Indeed it is less difficult to bring students than journeymen to comprehend and maintain a high shop standard.

The great difference between the two is not so much in the quality of the work as in the quantity, and this difference is very great indeed. This unexpected element in students comes out very clearly in the matter of injury to tools and spoiling work. It is my opinion that during the twenty-eight years of experience at the Worcester Polytechnic, notwithstanding the very large number of students, there was hardly a larger amount of work spoiled or more injury done to the tools than would have resulted if the large number of students had been replaced by average journeymen machinists.

To consider the second of the prominent features of the Half-time School, namely: "A school in which the pupils are to

have instruction and practice in the shop during half the working hours in five days of each week for a period of four years," I would call your attention to the

Importance of a Properly Arranged Hour-plan.

This subject is of greater importance in a school where shop practice is part of the course than in any other course of study, because it is so necessary that the periods in the shop should be as long as possible without danger of over-wearying the student. Therefore, it is very desirable that no period of shop practice be less than a half-day, and also that an afternoon period of practice be always followed by a like period by the same class the following forenoon; for example: a student would begin his weekly shop practice Monday afternoon at one o'clock; he would leave his working clothes near his work, on the lathe, for a free evening and a night's rest, without any anxiety about lessons, returning the next morning to take up his shop work where he left it, and continuing the same throughout the forenoon.

By this method the great advantage is secured of having, so far as the shop work is concerned, nothing shorter than a whole day's session, and, so far as the student is concerned, two half-day sessions, with an evening of recreation and a night's rest between.

A similar advantage of such an hour-plan obtains in regard to the work in the schoolroom.

How Much can be Accomplished for Students in the Half-time School in a Four Years' Course.

First.—We can confidently assure a more thorough expert knowledge of the machinist's trade, and a more practical skill in its various departments, than is generally secured by any apprenticeship in this country or Europe. This rather large expectation is based upon quite a thorough personal study of what is accomplished in England, France, Switzerland, and Germany, and also upon what has been accomplished during twenty-eight years at the Washburn shops of the Polytechnic Institute of Worcester, Mass.

In this school, where a 3½ years' course included only 2,376 hours of shop practice, or, in other words, less than one-third of a 3 years' apprenticeship, the graduates have always enjoyed a high reputation for practical skill and shop experience. And it

has been claimed throughout the history of the school that its graduates are as skilful and effective practical machinists as those who have served a 3 years' apprenticeship to learn the machinist's trade. This is a very bold claim, when it is remembered that together with this attainment of practical skill the graduate has obtained a thorough technical and scientific education. After a very thorough experience and after employing large numbers of these graduates in all capacities in machine shops, I think the claim is well sustained.

In the Half-time School actual shop practice in the various departments would cover a much longer time, and under circumstances more favorable, because the attainment of a thorough machinist's trade is confessedly the central point from which the future engineering work is to emanate.

Second.—These pupils will receive, as a part of their shop practice, a much larger amount of time in lectures and instruction upon the technical part of the machinist's business than is given in the technical school.

Third.—It is proposed to train every pupil in the general knowledge and practice of drawing and machine design, and any one having particular taste in this direction can have special and advanced instruction, the object being to make draughtsmen superior to engineering-school graduates in the following particulars:

(*a*) More expert in execution of drawing and lettering.

(*b*) Much more thoroughly familiar with all the shop knowledge affecting the efficiency of a draughtsman on simple everyday work.

(*c*) A more ready, reliable, and precise use of arithmetic.

Fourth.—It is proposed to train every pupil in a general knowledge and practice of pattern making and foundry moulding, and in special cases give advanced instruction and practice in pattern making. In all cases, however, the machinist's trade will be taught as the basis of any special line of mechanical work.

Fifth.—Pupils who exhibit suitable qualifications as workmen and as directors of men will have special opportunities to become fitted for responsible positions, as working machine-shop foremen. Such pupils, among other qualifications necessary for foremen, would be required to show general ability in drawing, pattern making, and special accuracy and reliability in arithmetic.

Sixth.—If any one from the above-mentioned classes of men exhibits taste and natural abilities for high-grade engineering work, requiring the highest mathematical and scientific knowledge, he will be encouraged and aided to take a course to meet his special requirements in an engineering school.

To consider the third of the prominent features already briefly stated, viz.: "Instruction in the public schools during a portion of the other half of the time, equivalent to a high-school course, restricted, abridged, and improved to meet the needs of these pupils."

What are the Duties and Responsibilities to be Assumed by the School Board?

The School Board of any town where it is proposed to establish one of these Half-time Schools must be induced to make what seems to be a most reasonable provision for a class of boys whose needs are as imperative and as reasonable as those of boys who wish to fit for college. Therefore, the present high-school course for this class should be changed and made especially suited to their needs. This is as reasonable a demand, if not more so, as the demand of the boy to be fitted for college.

The necessary provisions on the part of the public school consist in room and instruction for a certain number of boys. Only one-half of this number will be in the school-room at the same time. On the score of economy this arrangement will be greatly in favor of the Half-time School over the present method.

I have not thought it wise to burden this paper with the details of the course of study; suffice it to say, that I believe it possible to cover in the four years' course all the studies which a liberally educated mechanic will require, and at the same time to prepare him nearly or altogether to enter a technical school, if his ability and opportunity permit.

As to the fourth of the prominent features of the proposed school, viz.: "Special care and method of selection of pupils who have finished the grammar-school course, and who have special aptness for mechanical work," let us consider

The Importance of Good Material and the Selection of Students.

Do we get the best stock for engineers? We have the sons of engineers who stand first in the great industrial enterprises. The young men coming to the engineering schools are generally the best in many ways. They are usually well born; they do not often come from poor homes, where work, stern effort, and self-denial keep boys out of reach of the thorough systematic mental training which fits them for entrance examinations. If such a boy from the poor home finds it possible to enter, the college life is rather out of his line and out of his reach, and the funds for the term bills are still more impossible. But in this class are many who should be fitted for the different grades of mechanics.

It is well to remember, in the light of all history, that the revolutions of fate bring the submerged to the top, and after a while the child of fortune becomes enervated by advantageous ease and good keeping, and frequently the son, in spite of the father's determination to give him a better chance than he had, lacks something which has distinguished the father, and we may, after all, search this class in vain for the best stuff for engineers. It cannot, however, be the wisest educational scheme which allows the rich man's boy to degenerate, or merit to go undiscovered in the poorer classes, wherever it may exist.

There are marvellous possibilities of skill and invention among a class of boys who are never thought of as possible engineers, boys who sometimes make themselves leaders among the favored ones of the earth. In one of the largest and most prosperous industries near by I find that the man who knows the most about a very important department carried a hod when the factory was building ten years ago; and the responsible head of another department was snagging castings eight years ago. One of the fond hopes of the Half-time School is that it will pan out the pure metal by a sifting process which is true and fair; and selection of material is the first important step in the process. The selection of the pupils is only second in importance to the schooling itself.

The proper education of the American mechanic will not necessarily be sought after by the boy who is best capable to become the mechanic. He must be sought out and then trained. The American boy needs to be awakened to the inducements for becoming an educated mechanic. Many a boy who is splendidly

suited by nature and by inheritance to this calling is allowed by outside influences to drift into some other calling to which he is not adapted, all for the lack of a little guidance or some circumstance having no connection with his fitness or aptitude for mechanics, and thus is lost to the profession which needs him.

The hindrance to the best results in engineering schools, which has come from the imperfect and unfair method of selection in making up or enlisting its classes, has already been mentioned. Under the present system it is a boy's business to spend several years of cramming for examinations after he decides upon going to a polytechnic school or college. His whole aim and the aim of his teacher is to prepare for the examinations. The fitting school develops an astonishing ability to pass examinations which are not a true or adequate test of a boy's fitness to make a mechanic or a mechanical engineer. Therefore the entering class of the polytechnic institute consists of a body of experts at examinations, while the boys all through the country who ought to be trained for manufacturing and mechanical industry are overlooked and passed by.

It is proposed to avoid the bad defects due to this system in the Half-time School by providing

A Substitute for Entrance Examinations, or at Least a Supplement to Them.

An appointment to the Half-time School would be the result of careful, honest, quiet investigation into the boy's life, as to his habits of work and study, as to his personal habits of order, as to how he spends his evenings, Sundays, and holidays, as to his love and care of tools, and as to his tastes for mechanical work, especially as to what he has actually constructed with tools before he is fourteen years of age. All these facts can be collected from his neighbors and teachers, and so verified that more reliance may be placed on them than on any common entrance examination. Are not these things a truer indication of a boy's fitness for the life of a mechanic or engineer than the one single quality of being able to pass written examinations in recitations, such as the colleges require for entrance?

To consider the fifth of the features, already briefly stated—viz., "Management under a corporation whose trustees shall be practical business men"—let us look at

The Advantages of a Corporation for the Management of School Shops.

Perhaps the most successful technical schools have been organized by private corporations and managed by a board of trustees who have had all departments, scientific, practical, and literary, under their direction. It is believed that the plan proposed for the Half-time School, where a corporation is formed and a charter secured for doing exactly what the school shop wishes to do, will have great advantages over educational corporations as heretofore formed and chartered.

It is difficult at present, though not so difficult as it was twenty-five years ago, to find available men who are competent to assume the direction of both school and shop; and when this responsibility is divided and assigned to different men, the difficulties do not disappear.

A corporation chartered to conduct school shops independently of the book department of the school need not be limited, as our technical school corporations are. That is, they would be chartered to conduct a school shop solely for educational purposes by means of a commercial shop which would sell its products in the open market for the benefit of an educational institution.

One of the greatest objections to commercial productive shops in technical schools, and possibly the only real objection, has come from the complaint of local manufacturers, who make the narrow claim that an educational institution, exempt from taxation, has no right to enter into competition with other manufacturers who are obliged to pay taxes, and also obliged to pay all their help, while the students work without pay in school shops.

Of course this argument is not reasonable, since any manufacturer is at liberty to take students if he can offer them instruction and wages valuable and attractive enough to compensate them for their time. Nevertheless, this objection has had an influence and has been a hindrance to several of the most promising technical schools.

The trustees of the Half-time School shop would be business men chosen for their ability and practical knowledge in all manufacturing and mechanical industry, and especially for their interest in young men. These trustees would give their direct

attention to the control, direction, and approval of the acts of the superintendent in the conduct of the school shop and the management of its financial and business affairs. The superintendent would be a competent man, appointed and subject to removal by this board of trustees. All other officers and employees of the shops would be under the control of the superintendent.

While the responsibility of this board of trustees would be primarily centred upon the shop department of the school, the book department, which is supported and conducted by the public school board, would be largely influenced by them, and they would quite likely be members of the school board as well as trustees of the corporation.

The Financial Question regarding the Current Operation of School Shops after they have been established, equipped, and provided with a Working Capital.

Having briefly outlined the scope of the shop training for the pupils, it may be well to say a word regarding the business and financial aspect of school shops. The chances for financial support and success are not less than with industrial enterprises where the central object and motive is to make money. The advantages respecting the financial success of the enterprise are:

First.—The school shops would have a superior board of trustees who would serve without pay.

Second.—A property, equipment, and some working capital without interest, and possibly free from taxation.

Third.—The difficulties of establishing a reputation for reliability and excellent workmanship are no greater than in the case of ordinary shops.

Fourth.—Business can be secured to some extent through the good will and interest of gentlemen having faith in an enterprise to aid young men and advance the standing of American mechanics and mechanical engineers.

Fifth.—Although a large number of beginners in a shop bring great care and many perplexities, it must be insisted that fifty or a hundred young men, interested, earnest, well-disposed, enthusiastic, and energetic, bring a large amount of power, which may be indeed useful and valuable to the business when it is properly directed.

To carry out this plan there will be needed, besides a site:

For shop buildings	$20,000 to	$40,000
For equipment (machines and tools)	20,000 to	30,000
For material, raw, wrought, and in process, and accounts uncollected and cash for current business	40,000 to	60,000
Total	$80,000 to	$130,000

As a basis of confidence in the financial estimates for the maintenance of school shops I have exhibited as an appendix to this paper a sheet of statistics covering a period of twenty-seven years while I was superintendent of the Washburn Shops, a department of the Polytechnic Institute of Worcester, Mass., from May 1, 1869, to May 1, 1896.

This form of statement admits of ready comparison of facts from year to year, and for this reason it is belived to be more instructive than the usual form of report which was made by the superintendent annually, and from which this table is compiled. But for any reader who may not care to make a study of the table, I offer the following facts, which I take from the annual report to the trustees of the Institute at the end of the twenty-sixth year, namely:

For twenty-six years the *average annual financial gain* is $2,357.25. And the gain for the last five years is as follows:

1891	$4,567 80	1894	7,326 88
1892	5,487 87	1895	15,729 90
1893	11,814 83		

For the twenty-sixth year the sources of gain are as follows:

From general manufacturing	$4,285 21
From the manufacturing of grinding machinery	792 29
From the manufacturing of patented grinding machinery	3,709 06
From the manufacturing of hydraulic machinery	25,499 88
From interests on shop deposits	145 93
	$34,432 37
From apprentice tuitions	3,000 00
	$37,432 37

From Treasurer's Report.

Income W. M. S. Fund	2,539 50
Interest on deposits	126 55
	$40,098 42

The gain from the first items, which constitute the manufacturing business of the school shop, is the net difference between the cost in material and labor and the amounts collected as selling price. Therefore, from the gross gain of $40,089.42 we must deduct the amount of current expenses for the year, of $24,368.52, and get the net gain of $15,729.90.

The current expense is made up of all unproductive expenditures—coal, gas, insurance, etc.—and also the superintendent's salary, together with every hour of unproductive labor devoted to instruction, etc. This amounts to $19,868.52; and an allowance made to cover possible loss in collecting accounts, etc., $4,500—making the amount above stated, $24,368.52.

It should be said that in this showing no allowance is made for depreciation of real estate or equipment further than a liberal system of repairs and replacement of tools, this being the method designated by the founder, who provided a fund of $50,000, the income of which he wished to meet depreciation without charging the same to the account of the school shop.

Without including the income of this $50,000 fund, for the last five years the shops were more than *self-supporting*, as follows:

1891.....	$1,660 70	1894.....	$4,430 49
1892.....	2,637 48	1895.....	13,063 85
1893.....	9,189 71		

This is after $4,500 have been set aside to cover possible losses in collecting.

Referring to the financial statement appended—

Twenty-seven Years Compared.

It will appear that the average number of students in the shops for the twenty-seven years was 95.11, and for the last six years 167; that the average number of workmen employed for the twenty-seven years was 23.88, and for the last six years 57; that the average annual pay-roll (not including superintendent's salary) for the twenty-seven years was $15,305.37, and for the last six years it was $33,094.77; that the average amount paid for unproductive labor, chiefly for instruction, for the last twenty-seven years was $4,957.29, and for the last six years it was $11,271.35; that the shop profits—that is, the excess of selling price over the shop cost in material and labor and including the small tuition fees of the first year class—average for the twenty-seven years annually $10,694.64, and for the last six years $28,207.77;

that for four years out of the twenty-seven more money was paid into the treasury than was drawn or used for the entire needs of the business. (See note at bottom of table.)

Referring to column 5, it appears that the cash business of the shop—that is, collections—averaged for the twenty-seven years annually $3,189.71, and for the last six years annually $78,755.40.

It should not be overlooked that, notwithstanding this apparent overshadowing array of financial and business considerations, everything from first to last is made subservient to the interests and entirely for the best and highest educational advantages of the students, who are in these shops for what they can learn, and that their chances for becoming the most effective men are not to be hindered but enhanced by this atmosphere of real business. That the references for confirmation of my faith in the great possibilities of a real machine shop as the most effective means of education and of my faith in its feasibility wherever it is given a *fair chance* may not seem too local and too personal, I do not wish to confine your observation to the Worcester school, where a kind Providence decreed the better part of my life should be spent. But we have established similar school shops nearly equal in extent and importance in Virginia and in Georgia. In Atlanta, Ga., where I spent a year in assisting to establish the school shop, the result educationally was everything that could be desired and more than was expected.

The financial statement for the first year, even, was as follows—which, by the way, was as good in many ways as we were able to show at Worcester at the end of five years. To show the advantage of having a precedent to start from and to improve upon, the financial report of the Georgia School of Technology Shops for the first year (of nine months) from October 1, 1888, to July 1, 1889, is as follows:

Assets per inventory:	
Equipment at cost	$19,587 52
Material, raw, wrought, and in process	2,790 79
Total	$22,378 31
Sale of shop products:	
Cash collections	$9,076 90
Accounts in collection, less bills owed	514 46
Cash in shop office	306 82
The net cost of operating the shops the first year, not including the salary of the superintendent, which was met from other funds, was	1,865 78

Second Form Showing Same Results.

Total expenses as per ledger		$4,856 29
Amount lost from equipment		21 78
Total		$4,878 07
Profit made on manufacturing machinery	$1,688 05	
Profit made on manufacturing castings	1,324 26	
		3,012 31
The cost of running shops for the first fiscal year (nine months), not including superintendent's salary		1,865 78

There were about one hundred students in these shops, and the number of employed men varied from twenty to fifty.

There is so much labor necessary to complete the shops the first year that the amount of business is necessarily small, and the chances for self-support greatly reduced.

At the Miller School, Crozet, Va., where they have extensive shops and excellent equipment, situated in the midst of a country in great need of machinists and other mechanics, the school is so richly endowed and funds are so plenty that there has not as yet been much done beyond a high class of manual training. If this school would employ forty good skilled mechanics, and, with the abundance of iron, coal, and timber near at hand, manufacture $100,000 worth of school furniture, agricultural implements, and first-class machinists' tools each year, under the eye and with the help of one hundred students, who can estimate the effect upon the manufacturing and the mechanical industry of that grand old State?

Besides the chief features of the proposed Half-time School I would also refer to others of, perhaps, less importance, yet of value in such a scheme.

Vacations.

There is a great opportunity for improvement in the education of the boy offered by a radical change in the matter of vacations. The present method is to crowd the work of the week into five days, and the work of the year into thirty-five or thirty-seven weeks, making it as intense as possible for a while and then letting up entirely.

It is certainly not impossible to arrange a course of education and training of a boy with hard work so judiciously distributed and so interspersed with healthful, easy, and enjoyable exercises,

and so intermingled with daily (not quarterly or yearly) recreation, that he will never need or require entire or complete relief from duty. Nothing is so dangerous or so trying to a boy's nervous, mental, and physical constitution as the method of suddenly applied load and long intervals of total relief. Six days' work in a week, with sufficient variety, recreation, and healthful exercise distributed throughout each day, and with Sunday properly spent, will, I think, assure much better and more enjoyable effort on each following Monday than is possible where all the students' work is dropped for two days every week.

The same gain may be obtained by distributing the work throughout the eleven or twelve months of the year. I must not be understood as recommending harder or more work. I would make an easier course for boys, not a harder one, by having a better arrangement and distribution of an ample amount of daily work, rest, and recreation, and then instead of the present vacation, which is frequently harmful instead of helpful, I would grant *furloughs* to any student who needed or desired it. Such furloughs are not impossible or impracticable, and would be, in my judgment, much better and more effective than the present vacation seasons. Let it be understood that this presupposes a school organized for the good of the pupils and not for the convenience of the teachers.

Is there a Danger of Making the School Course too Severe?

It seems to me that this danger is very great, a danger that has already been realized, from time to time, in almost every institution of learning. Many methods have been resorted to to avert the danger—such as shortening terms of study, which necessarily makes them more condensed; the introduction of athletics, etc., which is apt to absorb enthusiasm needed for the work—and when I have suggested continuous school work, less vacations, and less interruptions, I insist that I do not believe in harder work but easier work for students, and I believe that a four years' course can be so arranged, with such interesting and profitable variety of occupation alternating between the recitation room, the draughting room, the pattern-making room, the machine shop, the shop lecture room, and with the requisite amount of exercise and recreation, not at long intervals, but in every half-day, that a boy's life from fifteen to nineteen would be a joy and not a burden.

Second Form Showing Same Result Possible.

Total expenses as per ledger.....
Amount lost from equipment.....

Total.....

Profit made on manufacturing mach
Profit made on manufacturing e

The cost of running shop
including superinten

There were
the numb
Ther
first
th

educated workmen, it but more years in school We have complaints on every course, and uncultivated, as well as to be a general belief that education existing evils among workmen—evils selfishness, jealousy, and narrowness effects of some forms of trades-union- if it is confined to the bookwork of the consisting largely of learning facts, will not in itself any more than the mere acquirement of skill. of the education needed by machinists, fore- The fact that men of culture are commonly has naturally led to a wrong conclusion as to the and to erroneous expectations regarding the of universal education for the evils of the work-

The scholastic work of the university is indeed but a small part of the good of the college life. Commonly the boy who enters college has inherited the elements of culture, and he leaves a home where all the early and formative portion of his life has been amid influences of refinement. Whatever additional culture he attains comes very largely from his social intercourse with superior men as instructors and from college life with his mates, who are, in most cases, his equals or superiors. We are likely to ascribe altogether too much credit to the learning acquired at college in the development of the man. I do not say this to disparage in the least the superior culture of the educated man. But a clear knowledge of the true source of this superiority is of vital importance in the consideration of my subject, especially the education of machinists. Book knowledge, however important and valuable it may be, is but a small part of the general education needed by the machinist and the foreman. From this fact, to a large extent, springs the confidence in the plan of technical education which this paper proposes. It proceeds upon the assumption that machinists need education and culture, and can make good use of them, and that it is possible to supply these within much less time than is usually devoted to scholastic work in the case of boys who are born in

more favored circles and are educated for the professions. Wonderful results can be obtained under favorable conditions in developing culture and the higher traits of character and mental discipline in the workshop, and possibly as effectively as in the schoolroom. It has never been proved that this is not entirely practicable. I am convinced of its soundness, and I think that its reasonableness is very evident. We cannot say that because culture has commonly been developed to the highest degree in scholars who have devoted themselves to the study of the dead languages and ancient history, etc., that it follows that they would not have become equally cultured had they devoted as much time and talent to the study of other and more practical subjects. There is good reason to believe that faithful devotion to the study of mechanics, mechanism, machine design, and similar work, leading to and including mechanical engineering, may prove to be the best possible lines of study for development of the highest and best mental qualities of man. Certainly no other line of human activity can so directly cultivate the creative powers of the human mind and develop the imagination. We hear of the artist's love of beauty. The mechanic may find beauty in a thousand places all through his work. He can be a designer and a sculptor in his own art. The scholar has a passion for truth. There is truth demanded and found everywhere in the realm of mechanics, and to find it and to be able to secure it is one object of the education of the mechanic. It is not denied that one source of culture comes through the acquirement of knowledge and skill, but this is only one means, and perhaps not the most important one. A more important source, as already mentioned, is by the intercourse with superior men and teachers, and this means of culture is just as possible in a machine shop as it is in a college, provided we can secure the superior men for teachers in the shops. In the past, conditions have been so unfavorable for the education of mechanics that it is difficult to appreciate at first thought the large possibilities of their future development in this direction.

How Shall we successfully Meet our Foreign Competitors?

America has made a strong beginning as an export nation of high-grade machinery. There are many evidences of the keen interest, amounting to surprise and alarm, on the part of our European rivals. It is interesting to note their efforts to dis-

cover the causes of this sudden uprising of a new and evidently powerful rival in a field heretofore all their own.

The cause of our supremacy has not been altogether the superiority of our engineers, for they also have highly educated engineers. But it has largely resulted from the superior character and make-up of our mechanics, which has come from the chance which America gives the workman, and in the liberal and wise provisions to train free-born American boys, giving each a fair field and open path to rise from one plane to a higher one as his abilities and circumstances may warrant.

We must not allow ourselves to rest secure in the belief that our Old World competitors will be slow to discern this cause or slow to profit by the example. Therefore, what more potent steps can we take for our protection than to keep this path open from the bottom and to better our methods all the way up through the successive steps?

FINANCIAL STATEMENT OF THE WASHBURN SHOPS OF THE WORCESTER POLYTECHNIC INSTITUTE. TWENTY-SEVEN YEARS COMPARED: MAY 1, 1869, TO MAY 1, 1896.

1	2	3	4	5	6
Business Year ends May 1st.	Cash received by Superintendent from the Treasurer.	Bills paid by Treasurer, not Entered in Shop Books.	Total Drafts on Shop Funds.	Proceeds of the Shop paid in to the Treasurer.	Amount Drawn exceeds Amount Paid in.
1st year—1870.	$11,729 81	$1,438 24	$13,168 05	$1,532 33	$11,635 72
2d year—1871.	13,187 26	1,110 45	14,297 71	4,964 05	9,333 66
3d year—1872.	19,998 94	996 00	20,994 94	14,224 31	6,770 63
4th year—1873.	19,191 10	810 80	20,001 90	11,437 84	8,564 06
5th year—1874.	15,474 57	1,114 87	16,589 44	10,274 41	6,315 03
6th year—1875.	17,676 29	1,045 58	18,721 87	16,751 25	1,970 62
7th year—1876.	15,931 56	882 04	16,813 60	12,175 19	4,638 41
8th year—1877.	18,556 74	832 21	19,388 95	16,908 70	2,480 25
9th year—1878.	18,360 03	728 50	19,088 53	19,296 94	*
10th year—1879.	14,836 73	914 88	15,751 61	14,009 52	1,742 09
11th year—1880.	19,273 17	758 27	20,031 44	15,352 17	4,679 27
12th year—1881.	21,342 39	901 30	22,243 69	21,320 70	922 99
13th year—1882.	26,359 54	1,070 55	27,430 09	23,832 24	3,597 85
14th year—1883.	36,505 21	1,338 10	37,843 31	33,163 58	4,679 73
15th year—1884.	22,808 42	484 66	23,293 08	19,537 24	3,755 84
16th year—1885.	20,914 94		20,914 94	17,925 39	2,989 55
17th year—1886.	22,652 31		22,652 31	19,242 83	3,409 48
18th year—1887.	24,508 84		24,508 84	22,538 84	1,970 00
19th year—1888.	34,995 42		34,995 42	30,318 33	4,677 09
20th year—1889.	31,918 77		31,918 77	29,940 42	1,978 35
21st year—1890.	40,908 93		40,908 93	33,770 47	7,138 46
22d year—1891.	52,552 86		52,552 86	48,937 11	3,615 75
23d year—1892.	79,842 87		79,842 87	73,056 59	6,786 28
24th year—1893.	81,302 62		81,302 62	85,902 40	*
25th year—1894.	71,722 50		71,722 50	78,611 96	*
26th year—1895.	83,985 82		83,985 82	76,996 59	6,989 23
27th year—1896.	99,779 74		99,779 74	109,027 78	*
Totals.....	$936,317 38	$14,426 45	$950,743 83	$861,049 18	$98,942 69
Averages.....	.....	.....	$35,212 73	$31,890 71	$3,664 54
Av. past 6 yrs.	.....	.....	$78,197 73	$78,755 40	$2,898 54

*9th year amount paid in exceeds amount drawn, $208 41.
24th " " " " " " 4,599 78.
25th " " " " " " 6,889 46.
27th " " " " " " 9,243 04.

FINANCIAL STATEMENT OF THE WASHBURN SHOPS OF THE WORCESTER POLYTECHNIC INSTITUTE. TWENTY-SEVEN YEARS COMPARED: MAY 1, 1869, TO MAY 1, 1896.—*Continued.*

	7	8	9	9½
Business Year ends May 1st.	Current expenses, including Salary of Superintendent.	Shop profits. Excess of selling price over cost in stock and labor.	**Balance** Met from $50,000 Fund.	More than self-supporting without any income from Endowment Fund.
1st year—1870..	$3,875 15	$1,060 87	$2,814 28	
2d year—1871..	5,069 89	2,085 45	2,984 44	
3d year—1872..	5,830 90	3,079 93	2,750 95	
4th year—1873..	6,621 74	3,831 93	2,789 81	
5th year—1874..	6,902 92	2,731 46	4,171 46	
6th year—1875..	7,096 47	3,717 48	3,378 99	
7th year—1876..	6,436 50	3,329 10	3,107 40	
8th year—1877..	6,700 42	3,619 21	3,081 21	
9th year—1878..	6,998 19	5,891 87	1,106 32	
10th year—1879..	6,759 74	4,487 40	2,272 34	
11th year—1880..	7,437 53	5,159 66	2,277 86	
12th year—1881..	7,745 01	6,657 72	1,087 29	
13th year—1882..	8,524 65	6,604 06	1,920 59	
14th year—1883..	10,069 07	7,504 43	2,564 64	
15th year—1884..	9,382 41	6,183 80	3,198 61	
16th year—1885..	9,210 86	6,151 32	3,059 54	
17th year—1886..	9,030 40	7,745 42	1,284 98	
18th year—1887..	10,047 55	8,463 59	**1,583 96**	
19th year—1888..	11,313 58	9,597 23	**1,716 35**	
20th year—1889..	11,305 84	9,218 96	**2,086 88**	
21st year—1890..	13,787 52	12,387 72	**1,399 80**	
22d year—1891..	15,054 01	16,714 71		$1,660 70
23d year—1892..	20,253 57	22,891 05		2,637 48
24th year—1893..	21,830 05	21,019 76		9,189 71
25th year—1894..	20,651 48	26,798 41		4,430 49
26th year—1895..	19,868 52	37,432 37		13,063 85
27th year—1896..	24,775 43	34,390 35		8,657 65
Totals.....	$292,579 39	$288,755 28	$50,637 70	$39,639 88
Averages.....	$10,836 27	$10,694 64	Net 10,997 82	
			Average 407 32	
Av. past 6 years.	$20,405 51	$28,207 77	.....	$6,606 64

(Apprentice Tuitions Included.)

FINANCIAL STATEMENT OF THE WASHBURN SHOPS OF THE WORCESTER POLYTECHNIC INSTITUTE. TWENTY-SEVEN YEARS COMPARED: MAY 1, 1869, TO MAY 1, 1896.—*Continued.*

	10	11	12	13	14
Business Year ends May 1st.	Income from Investments. Treas. Report.	Apprentice Tuitions.	Columns 10 and 11 added.	Yearly Loss.	Yearly Gain.
1st year—1870.	*$5,000 00		$5,000 00		$2,185 72
2d year—1871.	*3,500 00		3,500 00		515 56
3d year—1872.	*3,500 00		3,500 00		749 05
4th year—1873.	*3,500 00		3,500 00		710 19
5th year—1874.	*3,500 00		3,500 00	$671 46	
6th year—1875.	3,000 00	$200 00	3,200 00	178 99	
7th year—1876.	3,450 00	50 00	3,500 00		392 60
8th year—1877.	3,300 00	350 00	3,650 00		568 79
9th year—1878.	3,300 00	250 00	3,550 00		2,448 68
10th year—1879.	3,300 00	200 00	3,500 00		1,227 66
11th year—1880.	3,300 00	375 00	3,675 00		1,397 14
12th year—1881.	3,065 84	450 00	3,515 84		1,978 55
13th year—1882.	2,283 33	750 00	3,033 33		362 74
14th year—1883.	2,550 00	975 00	3,525 00	14 64	
15th year—1884.	2,600 79	825 00	3,425 79	597 82	
16th year—1885.	2,457 59	1,200 00	3,657 59	601 95	
17th year—1886.	2,467 82	825 00	3,292 82		1,182 84
18th year—1887.	2,588 84	675 00	3,263 84		1,004 38
19th year—1888.	2,927 24	750 00	3,677 24		1,210 89
20th year—1889.	2,915 91	375 00	3,290 91		829 06
21st year—1890.	3,067 29	2,550 00	5,617 29		1,667 49
22d year—1891.	2,907 10	1,575 00	4,482 10		4,567 80
23d year—1892.	2,850 39	4,070 00	6,920 39		5,487 87
24th year—1893.	2,625 12	4,575 00	7,200 12		11,814 83
25th year—1894.	2,896 39	3,032 00	5,928 39		7,326 88
26th year—1895.	2,666 05	3,000 00	5,666 05		†15,729 90
27th year—1896.	2,467 89	3,000 00	5,467 89		11,125 54
Totals	$81,987 09	$30,052 00	$112,039 09	$2,064 86	$74,479 13
Net	.....	.....	.....	.....	$72,414 27
Average	.....	.....	.....	.....	2,682 01
Av. past 6 yrs.	$2,735 49	$3,208 66	$5,944 15	.....	9,342 13

* We have no copy of Treasurer's report for the first five years. These items marked are the anticipated income, as printed in the earlier Shop Reports.

† This is after $4,500 have been set aside to cover possible losses in collecting.

The gain from the first items, which constitute the manufacturing business of the school shop, is the net difference between the cost in material and labor and the amounts collected as selling price. Therefore, from the gross gain of $40,089.42 we must deduct the amount of current expenses for the year, of $24,368.52, and get the net gain of $15,729.90.

The current expense is made up of all unproductive expenditures—coal, gas, insurance, etc.—and also the superintendent's salary, together with every hour of unproductive labor devoted to instruction, etc. This amounts to $19,868.52; and an allowance made to cover possible loss in collecting accounts, etc., $4,500—making the amount above stated, $24,368.52.

It should be said that in this showing no allowance is made for depreciation of real estate or equipment further than a liberal system of repairs and replacement of tools, this being the method designated by the founder, who provided a fund of $50,000, the income of which he wished to meet depreciation without charging the same to the account of the school shop.

Without including the income of this $50,000 fund, for the last five years the shops were more than *self-supporting*, as follows:

1891	$1,660 70	1894	$4,430 49
1892	2,637 48	1895	13,063 85
1893	9,189 71		

This is after $4,500 have been set aside to cover possible losses in collecting.

Referring to the financial statement appended—

Twenty-seven Years Compared.

It will appear that the average number of students in the shops for the twenty-seven years was 95.11, and for the last six years 167; that the average number of workmen employed for the twenty-seven years was 23.88, and for the last six years 57; that the average annual pay-roll (not including superintendent's salary) for the twenty-seven years was $15,305.37, and for the last six years it was $33,094.77; that the average amount paid for unproductive labor, chiefly for instruction, for the last twenty-seven years was $4,957.29, and for the last six years it was $11,271.35; that the shop profits—that is, the excess of selling price over the shop cost in material and labor and including the small tuition fees of the first year class—average for the twenty-seven years annually $10,694.64, and for the last six years $28,207.77;

that for four years out of the twenty-seven more money was paid into the treasury than was drawn or used for the entire needs of the business. (See note at bottom of table.)

Referring to column 5, it appears that the cash business of the shop—that is, collections—averaged for the twenty-seven years annually $3,189.71, and for the last six years annually $78,755.40.

It should not be overlooked that, notwithstanding this apparent overshadowing array of financial and business considerations, everything from first to last is made subservient to the interests and entirely for the best and highest educational advantages of the students, who are in these shops for what they can learn, and that their chances for becoming the most effective men are not to be hindered but enhanced by this atmosphere of real business. That the references for confirmation of my faith in the great possibilities of a real machine shop as the most effective means of education and of my faith in its feasibility wherever it is given a *fair chance* may not seem too local and too personal, I do not wish to confine your observation to the Worcester school, where a kind Providence decreed the better part of my life should be spent. But we have established similar school shops nearly equal in extent and importance in Virginia and in Georgia. In Atlanta, Ga., where I spent a year in assisting to establish the school shop, the result educationally was everything that could be desired and more than was expected.

The financial statement for the first year, even, was as follows—which, by the way, was as good in many ways as we were able to show at Worcester at the end of five years. To show the advantage of having a precedent to start from and to improve upon, the financial report of the Georgia School of Technology Shops for the first year (of nine months) from October 1, 1888, to July 1, 1889, is as follows:

Assets per inventory:	
Equipment at cost	$19,587 52
Material, raw, wrought, and in process	2,790 79
Total	$22,378 31
Sale of shop products:	
Cash collections	$9,076 90
Accounts in collection, less bills owed	514 46
Cash in shop office	306 82
The net cost of operating the shops the first year, not including the salary of the superintendent, which was met from other funds, was	1,865 78

Second Form Showing Same Results.

Total expenses as per ledger		$4,856 29
Amount lost from equipment		21 78
Total		$4,878 07
Profit made on manufacturing machinery	$1,688 05	
Profit made on manufacturing castings	1,324 26	
		3,012 31
The cost of running shops for the first fiscal year (nine months), not including superintendent's salary		1,865 78

There were about one hundred students in these shops, and the number of employed men varied from twenty to fifty.

There is so much labor necessary to complete the shops the first year that the amount of business is necessarily small, and the chances for self-support greatly reduced.

At the Miller School, Crozet, Va., where they have extensive shops and excellent equipment, situated in the midst of a country in great need of machinists and other mechanics, the school is so richly endowed and funds are so plenty that there has not as yet been much done beyond a high class of manual training. If this school would employ forty good skilled mechanics, and, with the abundance of iron, coal, and timber near at hand, manufacture $100,000 worth of school furniture, agricultural implements, and first-class machinists' tools each year, under the eye and with the help of one hundred students, who can estimate the effect upon the manufacturing and the mechanical industry of that grand old State?

Besides the chief features of the proposed Half-time School I would also refer to others of, perhaps, less importance, yet of value in such a scheme.

Vacations.

There is a great opportunity for improvement in the education of the boy offered by a radical change in the matter of vacations. The present method is to crowd the work of the week into five days, and the work of the year into thirty-five or thirty-seven weeks, making it as intense as possible for a while and then letting up entirely.

It is certainly not impossible to arrange a course of education and training of a boy with hard work so judiciously distributed and so interspersed with healthful, easy, and enjoyable exercises,

and so intermingled with daily (not quarterly or yearly) recreation, that he will never need or require entire or complete relief from duty. Nothing is so dangerous or so trying to a boy's nervous, mental, and physical constitution as the method of suddenly applied load and long intervals of total relief. Six days' work in a week, with sufficient variety, recreation, and healthful exercise distributed throughout each day, and with Sunday properly spent, will, I think, assure much better and more enjoyable effort on each following Monday than is possible where all the students' work is dropped for two days every week.

The same gain may be obtained by distributing the work throughout the eleven or twelve months of the year. I must not be understood as recommending harder or more work. I would make an easier course for boys, not a harder one, by having a better arrangement and distribution of an ample amount of daily work, rest, and recreation, and then instead of the present vacation, which is frequently harmful instead of helpful, I would grant *furloughs* to any student who needed or desired it. Such furloughs are not impossible or impracticable, and would be, in my judgment, much better and more effective than the present vacation seasons. Let it be understood that this presupposes a school organized for the good of the pupils and not for the convenience of the teachers.

Is there a Danger of Making the School Course too Severe?

It seems to me that this danger is very great, a danger that has already been realized, from time to time, in almost every institution of learning. Many methods have been resorted to to avert the danger—such as shortening terms of study, which necessarily makes them more condensed; the introduction of athletics, etc., which is apt to absorb enthusiasm needed for the work—and when I have suggested continuous school work, less vacations, and less interruptions, I insist that I do not believe in harder work but easier work for students, and I believe that a four years' course can be so arranged, with such interesting and profitable variety of occupation alternating between the recitation room, the draughting room, the pattern-making room, the machine shop, the shop lecture room, and with the requisite amount of exercise and recreation, not at long intervals, but in every half-day, that a boy's life from fifteen to nineteen would be a joy and not a burden.

Development of Culture in the Shops Possible.

Although, of course, we want better educated workmen, it does not follow that they need nothing but more years in school before they go into the shops. We have complaints on every hand that workmen are dull, coarse, and uncultivated, as well as ignorant; and there seems to be a general belief that education would remedy many of the existing evils among workmen—evils which spring up from the selfishness, jealousy, and narrowness which lead to all the bad effects of some forms of trades-unionism. But education, if it is confined to the bookwork of the classroom, consisting largely of learning facts, will not in itself remedy these evils any more than the mere acquirement of skill. This is only a part of the education needed by machinists, foremen, or engineers. The fact that men of culture are commonly university men has naturally led to a wrong conclusion as to the effect of education and to erroneous expectations regarding the remedial effects of universal education for the evils of the working classes.

The scholastic work of the university is indeed but a small part of the good of the college life. Commonly the boy who enters college has inherited the elements of culture, and he leaves a home where all the early and formative portion of his life has been amid influences of refinement. Whatever additional culture he attains comes very largely from his social intercourse with superior men as instructors and from college life with his mates, who are, in most cases, his equals or superiors. We are likely to ascribe altogether too much credit to the learning acquired at college in the development of the man. I do not say this to disparage in the least the superior culture of the educated man. But a clear knowledge of the true source of this superiority is of vital importance in the consideration of my subject, especially the education of machinists. Book knowledge, however important and valuable it may be, is but a small part of the general education needed by the machinist and the foreman. From this fact, to a large extent, springs the confidence in the plan of technical education which this paper proposes. It proceeds upon the assumption that machinists need education and culture, and can make good use of them, and that it is possible to supply these within much less time than is usually devoted to scholastic work in the case of boys who are born in

more favored circles and are educated for the professions. Wonderful results can be obtained under favorable conditions in developing culture and the higher traits of character and mental discipline in the workshop, and possibly as effectively as in the schoolroom. It has never been proved that this is not entirely practicable. I am convinced of its soundness, and I think that its reasonableness is very evident. We cannot say that because culture has commonly been developed to the highest degree in scholars who have devoted themselves to the study of the dead languages and ancient history, etc., that it follows that they would not have become equally cultured had they devoted as much time and talent to the study of other and more practical subjects. There is good reason to believe that faithful devotion to the study of mechanics, mechanism, machine design, and similar work, leading to and including mechanical engineering, may prove to be the best possible lines of study for development of the highest and best mental qualities of man. Certainly no other line of human activity can so directly cultivate the creative powers of the human mind and develop the imagination. We hear of the artist's love of beauty. The mechanic may find beauty in a thousand places all through his work. He can be a designer and a sculptor in his own art. The scholar has a passion for truth. There is truth demanded and found everywhere in the realm of mechanics, and to find it and to be able to secure it is one object of the education of the mechanic. It is not denied that one source of culture comes through the acquirement of knowledge and skill, but this is only one means, and perhaps not the most important one. A more important source, as already mentioned, is by the intercourse with superior men and teachers, and this means of culture is just as possible in a machine shop as it is in a college, provided we can secure the superior men for teachers in the shops. In the past, conditions have been so unfavorable for the education of mechanics that it is difficult to appreciate at first thought the large possibilities of their future development in this direction.

How Shall we successfully Meet our Foreign Competitors?

America has made a strong beginning as an export nation of high-grade machinery. There are many evidences of the keen interest, amounting to surprise and alarm, on the part of our European rivals. It is interesting to note their efforts to dis-

cover the causes of this sudden uprising of a new and evidently powerful rival in a field heretofore all their own.

The cause of our supremacy has not been altogether the superiority of our engineers, for they also have highly educated engineers. But it has largely resulted from the superior character and make-up of our mechanics, which has come from the chance which America gives the workman, and in the liberal and wise provisions to train free-born American boys, giving each a fair field and open path to rise from one plane to a higher one as his abilities and circumstances may warrant.

We must not allow ourselves to rest secure in the belief that our Old World competitors will be slow to discern this cause or slow to profit by the example. Therefore, what more potent steps can we take for our protection than to keep this path open from the bottom and to better our methods all the way up through the successive steps?

FINANCIAL STATEMENT OF THE WASHBURN SHOPS OF THE WORCESTER POLYTECHNIC INSTITUTE. TWENTY-SEVEN YEARS COMPARED: MAY 1, 1869, TO MAY 1, 1896.

1	2	3	4	5	6
Business Year ends May 1st.	Cash received by Superintendent from the Treasurer.	Bills paid by Treasurer, not Entered in Shop Books.	Total Drafts on Shop Funds.	Proceeds of the Shop paid in to the Treasurer.	Amount Drawn exceeds Amount Paid in.
1st year—1870.	$11,729 81	$1,438 24	$13,168 05	$1,532 33	$11,635 72
2d year—1871.	13,187 26	1,110 45	14,297 71	4,964 05	9,333 66
3d year—1872.	19,998 94	996 00	20,994 94	14,224 81	6,770 63
4th year—1873.	19,191 10	810 80	20,001 90	11,437 84	8,564 06
5th year—1874.	15,474 57	1,114 87	16,589 44	10,274 41	6,315 03
6th year—1875.	17,676 29	1,045 58	18,721 87	16,751 25	1,970 62
7th year—1876.	15,931 56	882 04	16,813 60	12,175 19	4,638 41
8th year—1877.	18,556 74	832 21	19,388 95	16,908 70	2,480 25
9th year—1878.	18,360 03	728 50	19,088 53	19,296 94	*
10th year—1879.	14,836 73	914 88	15,751 61	14,009 52	1,742 09
11th year—1880.	19,273 17	758 27	20,031 44	15,352 17	4,679 27
12th year—1881.	21,342 39	901 30	22,243 69	21,320 70	922 99
13th year—1882.	26,359 54	1,070 55	27,430 09	23,832 24	3,597 85
14th year—1883.	36,505 21	1,338 10	37,843 31	33,163 58	4,679 73
15th year—1884.	22,808 42	484 66	23,293 08	19,537 24	3,755 84
16th year—1885.	20,914 94		20,914 94	17,925 39	2,989 55
17th year—1886.	22,652 31		22,652 31	19,242 83	3,409 48
18th year—1887.	24,508 84		24,508 84	22,538 84	1,970 00
19th year—1888.	34,995 42		34,995 42	30,318 33	4,677 09
20th year—1889.	31,918 77		31,918 77	29,940 42	1,978 35
21st year—1890.	40,908 93		40,908 93	33,770 47	7,138 46
22d year—1891.	52,552 86		52,552 86	48,937 11	3,615 75
23d year—1892.	79,842 87		79,842 87	73,056 59	6,786 28
24th year—1893.	81,302 62		81,302 62	85,902 40	*
25th year—1894.	71,722 50		71,722 50	78,611 96	*
26th year—1895.	83,985 82		83,985 82	76,996 59	6,989 23
27th year—1896.	99,779 74		99,779 74	109,027 78	*
Totals.....	$936,317 38	$14,426 45	$950,743 83	$861,049 18	$98,942 69
Averages.....	.....	.....	$35,212 73	$31,890 71	$3,664 54
Av. past 6 yrs.	.....	.....	$78,197 73	$78,755 40	$2,898 54

*9th year amount paid in exceeds amount drawn, $208 41.
24th " " " " " " 4,599 78.
25th " " " " " " 6,889 46.
27th " " " " " " 9,248 04.

FINANCIAL STATEMENT OF THE WASHBURN SHOPS OF THE WORCESTER POLYTECHNIC INSTITUTE. TWENTY-SEVEN YEARS COMPARED: MAY 1, 1869, TO MAY 1, 1896.—*Continued.*

	7	8	9	9½
Business Year ends May 1st.	Current expenses, including Salary of Superintendent.	Shop profits. Excess of selling price over cost in stock and labor.	**Balance** Met from $50,000 Fund.	More than self-supporting without any income from Endowment Fund.
1st year—1870..	$3,875 15	$1,060 87	**$2,814 28**	
2d year—1871..	5,069 89	2,085 45	**2,984 44**	
3d year—1872..	5,830 90	3,079 95	**2,750 95**	
4th year—1873..	6,621 74	3,831 93	**2,789 81**	
5th year—1874..	6,902 92	2,731 46	**4,171 46**	
6th year—1875..	7,096 47	3,717 48	**3,378 99**	
7th year—1876..	6,436 50	3,329 10	**3,107 40**	
8th year—1877..	6,700 42	3,619 21	**3,081 21**	
9th year—1878..	6,998 19	5,891 87	**1,106 32**	
10th year—1879..	6,759 74	4,487 40	**2,272 34**	
11th year—1880..	7,437 52	5,159 66	**2,277 86**	
12th year—1881..	7,745 01	6,657 72	**1,087 29**	
13th year—1882..	8,524 65	6,604 06	**1,920 59**	
14th year—1883..	10,069 07	7,504 43	**2,564 64**	
15th year—1884..	9,382 41	6,183 80	**3,198 61**	
16th year—1885..	9,210 86	6,151 32	**3,059 54**	
17th year—1886..	9,030 40	7,745 42	**1,284 98**	
18th year—1887..	10,047 55	8,463 59	**1,583 96**	
19th year—1888..	11,313 58	9,597 23	**1,716 35**	
20th year—1889..	11,305 84	9,218 96	**2,086 88**	
21st year—1890..	13,787 52	12,387 72	**1,399 80**	
22d year—1891..	15,054 01	16,714 71		$1,660 70
23d year—1892..	20,253 57	22,891 05		2,637 48
24th year—1893..	21,830 05	21,019 76		9,189 71
25th year—1894..	20,651 48	26,798 41		4,430 49
26th year—1895..	19,868 52	37,432 37		13,063 85
27th year—1896..	24,775 43	34,390 35		8,657 65
Totals.....	$292,579 39	$288,755 28	$50,637 70	$39,639 88
Averages.....	$10,836 27	$10,694 64	Net 10,997 82	
		Average	..... 407 32	
Av. past 6 years.	$20,405 51	$28,207 77	.....	$6,606 64

(Apprentice Tuitions included.)

FINANCIAL STATEMENT OF THE WASHBURN SHOPS OF THE WORCESTER POLYTECHNIC INSTITUTE. TWENTY-SEVEN YEARS COMPARED: MAY 1, 1869, TO MAY 1, 1896.—*Continued.*

	10	11	12	13	14
Business Year ends May 1st.	Income from Investments. Treas. Report.	Apprentice Tuitions.	Columns 10 and 11 added.	Yearly Loss.	Yearly Gain.
1st year—1870.	*$5,000 00		$5,000 00		$2,185 72
2d year—1871.	*3,500 00		3,500 00		515 56
3d year—1872.	*3,500 00		3,500 00		749 05
4th year—1873.	*3,500 00		3,500 00		710 19
5th year—1874.	*3,500 00		3,500 00	$671 46	
6th year—1875.	3,000 00	$200 00	3,200 00	178 99	
7th year—1876.	3,450 00	50 00	3,500 00		392 60
8th year—1877.	3,300 00	350 00	3,650 00		568 79
9th year—1878.	3,300 00	250 00	3,550 00		2,443 68
10th year—1879.	3,300 00	200 00	3,500 00		1,227 66
11th year—1880.	3,300 00	375 00	3,675 00		1,397 14
12th year—1881.	3,065 84	450 00	3,515 84		1,978 55
13th year—1882.	2,283 33	750 00	3,033 33		362 74
14th year—1883.	2,550 00	975 00	3,525 00	14 64	
15th year—1884.	2,600 79	825 00	3,425 79	597 82	
16th year—1885.	2,457 59	1,200 00	3,657 59	601 95	
17th year—1886.	2,467 82	825 00	3,292 82		1,182 84
18th year—1887.	2,588 34	675 00	3,263 34		1,004 38
19th year—1888.	2,927 24	750 00	3,677 24		1,210 89
20th year—1889.	2,915 91	375 00	3,290 91		829 05
21st year—1890.	3,067 29	2,550 00	5,617 29		1,667 49
22d year—1891.	2,907 10	1,575 00	4,482 10		4,567 80
23d year—1892.	2,850 39	4,070 00	6,920 39		5,487 87
24th year—1893.	2,625 12	4,575 00	7,200 12		11,814 83
25th year—1894.	2,896 39	3,032 00	5,928 39		7,326 88
26th year—1895.	2,666 05	3,000 00	5,666 05		†15,729 90
27th year—1896.	2,467 89	3,000 00	5,467 89		11,125 54
Totals	$81,987 09	$30,052 00	$112,039 09	$2,064 86	$74,479 13
Net	.....	.....	.....	.....	$72,414 27
Average	.....	.....	.....	.....	2,682 01
Av. past 6 yrs.	$2,735 49	$3,208 66	$5,944 15	.....	9,342 13

* We have no copy of Treasurer's report for the first five years. These items marked are the anticipated income, as printed in the earlier Shop Reports.

† This is after $4,500 have been set aside to cover possible losses in collecting.

FINANCIAL STATEMENT OF THE WASHBURN SHOPS OF THE WORCESTER POLYTECHNIC INSTITUTE. TWENTY-SEVEN YEARS COMPARED: MAY 1, 1869, TO MAY 1, 1896.—*Continued.*

	15	16	17	18	19
Business Year ends May 1st.	Labor Charges to Expense, chiefly Instruction.	Paid for Productive Labor.	Pay Roll.	Average Number of Workmen employed.	Whole Number of Students in Shop.
1st year—1870.	$266 10	$4,530 04	$4,796 14	6	20
2d year—1871.	955 29	5,377 03	6,332 32	8	20
3d year—1872.	2,009 17	7,284 60	9,293 77	11	48
4th year—1873.	2,200 32	6,493 53	8,693 85	10	56
5th year—1874.	2,437 34	5,560 74	7,998 08	8	52
6th year—1875.	2,846 02	5,286 85	8,132 87	10	63
7th year—1876.	2,460 20	4,207 38	6,667 58	10	67
8th year—1877.	2,597 18	5,581 07	8,178 25	10	59
9th year—1878.	2,592 41	4,203 03	6,795 44	10	53
10th year—1879.	2,419 22	4,194 50	6,613 72	10	55
11th year—1880.	3,038 73	4,671 00	7,709 73	11	60
12th year—1881.	3,036 04	5,643 52	8,679 56	12	69
13th year—1882.	3,933 38	8,821 91	12,755 29	18	90
14th year—1883.	4,267 61	9,211 19	13,478 80	19	96
15th year—1884.	3,944 64	6,648 09	10,592 73	16	100
16th year—1885.	3,927 62	6,157 25	10,084 87	16	106
17th year—1886.	3,640 00	6,953 46	10,593 46	17	110
18th year—1887.	3,944 00	8,140 22	12,084 22	20	102
19th year—1888.	4,317 00	12,349 27	16,666 27	31	105
20th year—1889.	5,217 33	12,511 97	17,729 30	30	115
21st year—1890.	6,169 09	14,630 86	20,799 95	38	117
22d year—1891.	6,391 59	17,635 57	24,027 16	43	145
23d year—1892.	9,506 45	23,614 65	33,121 10	55	184
24th year—1893.	12,058 73	23,657 21	35,715 94	55	205
25th year—1894.	12,278 62	19,323 95	31,602 57	48	179
26th year—1895.	12,133 65	20,241 84	32,375 49	53	135
27th year—1896.	15,259 10	26,467 26	41,726 36	70	157
Totals	$133,846 83	$279,397 99	$413,244 82		
Averages	$4,957 29	$10,348 07	$15,305 37		
Av. past 6 yrs..	$11,271 35	$21,823 41	$33,094 77	54	167

FINANCIAL STATEMENT OF THE WASHBURN SHOPS OF THE WORCESTER POLYTECHNIC INSTITUTE. TWENTY-SEVEN YEARS COMPARED: MAY 1, 1869, TO MAY 1, 1896.—*Continued.*

	20	21	22	23	24
Business Year ends May 1st.	Paid Students for extra work in vacation.	Equipment.	Patterns.	Materials and Products in Process.	Columns 21-22-23 Added.
1st year—1870..	$53 16	$8,377 28	$516 72	$2,884 66	$11,778 66
2d year—1871..	173 16	12,594 91	759 19	3,407 67	16,761 77
3d year—1872..	603 68	14,219 38	970 31	4,578 44	19,768 13
4th year—1873..	213 89	15,415 91	1,116 22	7,689 72	24,221 85
5th year—1874..	99 14	15,986 84	1,366 65	8,194 52	25,548 01
6th year—1875..	166 92	16,162 08	1,432 18	7,897 50	25,491 76
7th year—1876..	152 82	16,232 49	1,507 23	6,547 27	24,286 99
8th year—1877..	67 05	16,855 93	1,512 08	8,807 59	27,175 60
9th year—1878..	90 74	16,997 11	1,544 55	5,049 00	23,590 66
10th year—1879..	395 52	17,069 38	1,544 55	5,905 78	24,519 74
11th year—1880..	397 52	17,454 98	1,544 55	6,888 84	25,888 37
12th year—1881..	173 19	17,619 53	1,554 19	5,368 72	24,542 44
13th year—1882..	133 65	17,718 01	1,554 19	7,289 84	26,562 04
14th year—1883..	265 48	18,563 67	1,063 09	7,210 51	26,837 27
15th year—1884..	50 90	18,766 97	1,613 84	9,025 16	29,405 97
16th year—1885..	72 50	19,119 01	2,003 41	9,791 61	30,914 03
17th year—1886..	66 76	19,918 37	2,043 19	9,520 99	31,482 55
18th year—1887..	87 52	20,829 22	2,070 30	10,748 58	33,648 10
19th year—1888..	79 45	20,985 31	2,138 65	13,476 04	36,600 00
20th year—1889..	22 99	21,651 24	2,180 43	12,650 25	36,481 92
21st year—1890..	103 65	23,256 09	2,465 48	14,499 98	40,221 55
22d year—1891..		24,349 68	2,545 04	13,775 80	40,670 52
23d year—1892..		30,127 64	2,882 56	19,347 47	52,357 67
24th year—1893..		31,177 46	1,576 19	21,249 50	54,003 15
25th year—1894..		33,643 98	*	20,366 88	54,010 86
26th year—1895..		34,391 14	233 87	25,787 95	60,412 96
27th year—1896..		34,799 43	732 81	†30,003 22	65,535 46

Annual Inventories, not including Boilers, Engine, Shafting, Benches, Piping, &c., $3,470. (Inv. Book, page 4.) Also this does not include any Real Estate.

* Pattern account, $1,680.66, charged off.

† Including "Shafting and Prep. Room changes."

FINANCIAL STATEMENT OF THE WASHBURN SHOPS OF THE WORCESTER POLYTECHNIC INSTITUTE. TWENTY-SEVEN YEARS COMPARED: MAY 1, 1869, TO MAY 1, 1896.—*Concluded.*

	25	26	27	28	29
Business Year ends May 1st.	Accounts and Cash.	Total Assets.*	Repairs.		
1st year—1870	†$429 65	†$12,208 31			
2d year—1871	†1,102 00	†17,863 77			
3d year—1872	†2,281 99	†22,050 12			
4th year—1873	†3,602 52	†27,824 34			
5th year—1874	†4,419 93	†29,967 94			
6th year—1875	†3,437 14	†28,928 90			
7th year—1876	4,801 75	29,088 74			
8th year—1877	2,481 93	29,657 53			
9th year—1878	8,510 55	32,101 21			
10th year—1879	8,809 16	33,328 87			
11th year—1880	8,837 64	34,726 01			
12th year—1881	12,162 12	36,704 56			
13th year—1882	10,505 26	37,067 30			
14th year—1883	10,215 39	37,052 66			
15th year—1884	7,083 05	36,489 02			
16th year—1885	4,973 04	35,887 07			
17th year—1886	5,587 36	37,069 91	$900 00		
18th year—1887	4,426 19	38,074 29	872 31		
19th year—1888	7,685 18	44,285 18	742 08		
20th year—1889	8,632 29	45,114 21	785 31		
21st year—1890	6,560 15	46,781 70	978 88		
22d year—1891	13,678 98	54,349 50	1,429 31		
23d year—1892	11,479 70	63,837 37	1,683 91		
24th year—1893	21,649 05	75,652 20	1,571 55		
25th year—1894	28,968 22	82,979 08	1,198 10		
26th year—1895	38,296 02	98,708 98	347 26		
27th year—1896	‡29,299 06	109,834 52	337 46		
Totals	.....	.....	$10,846 17		
Aver. past 6 yrs.	.....	.....	$1,094 59		

* The yearly assets are increased by the yearly gains (see column 14) and also by gifts.

† See note, page 3. The full figures from Treasurer's Report will vary these amounts.

‡ Includes the "Kent & Stanley Stock," amounting to $3,230.

No. 851.*

DISCUSSION ON PAPER NO. 850.—THE EDUCATION OF MACHINISTS, FOREMEN, AND MECHANICAL ENGINEERS.

BY MILTON P. HIGGINS, WORCESTER, MASS.

Rear Admiral George W. Melville.—I have read with great care and interest the most excellent paper by Mr. M. P. Higgins on the "Education of Machinists, Foremen, and Mechanical Engineers," and his very clear theory and explanation of his Half-time School shops.

The subject of his paper should be one of vital importance to the members of the Society. He shows deep insight into the needs of the hour for technical training of the youth, and his experience and thought upon this matter, as well as able presentation of his views, command earnest attention.

Mr. Higgins's theory for the education of the American youth with mechanical bent is that of natural development, stopping at the point where he has attained his utmost capacity. His theory seems most perfect. A special school is outlined which would, he claims, work out this theory for all mechanical schools, and the practical proof is the principal object of his paper. His purpose to give the youth a common-school education at the same time he learns a trade is a most praiseworthy if perhaps a somewhat ideal one. So far as possible, though, it certainly should be done. His paper is directed particularly to "those who dwell within the broad zone of the AVERAGE," and as such should appeal with telling force.

Mr. Higgins realizes that a trade itself is not sufficient, and that a higher education does not necessarily insure practical success. An education is the dream of many a poor boy, and many cannot get it; again, much money is often spent by parents who can ill afford it, and whose fond hopes for their son are dashed by his miserable failure in life. All this he would better, if possible.

---

* Presented at the New York meeting (December, 1899) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*. The interest excited by this paper, and the value and volume of the discussion upon it, have made it appear wise to present them as separate pamphlet issues numbered 850 and 851.

I find his paper most stimulating to thought, and as an arraignment of the existing order, as a possible look into better things (resulting from an appreciation of present defects), should not be without fruit.

I shall now present some thoughts which occurred to me when reading this paper, and here and there I shall take up a specific point touched on by Mr. Higgins and comment thereon. I must plead lack of time for the generality, in many instances, of my remarks, but I have tried always to indicate clearly the lines on which the detailed views would be carried out.

No gentleman here present will deny for a second of time the necessity of a higher education for every citizen of the United States, if possible; not only of the machinist and mechanic (the standard for whom Mr. Higgins recognizes has become much higher), but also of the laboring classes, or, in other words, the hard workers and the bread-winners of both sexes. For we can all agree, all things being equal, the educated and thoughtful worker can and does turn out more and better work than the uneducated worker, be the worker man or woman. (It is needless to add that the new and the better will ever replace the old and the worthless, since that is the law of change, of progress.)

But we must not lose sight of the fact that the large majority of the working classes of all nations are poor; and that because of their poverty, if for no other reason, they have to commence very early in life to earn their own living; *i.e.*, add their share, no matter how small it may be, to the family fund, for the general support of the whole household.

This will account for the large percentage of the public-school scholars who drop out of the school system before attaining to the high school—by Mr. Higgins said to be about 80 per cent.; and more than 97 per cent. of all public-school scholars, from the primary grades to the high school, drop out before graduation from that school. I fear that if this matter was fully investigated we should find it was because of the dire necessity of poverty, or the necessity for every one of these poor little bread-winners to at once, or at an early age, work for a living.

This being the case, the question in my mind is whether the public schools of this great country are not a great deal to blame for the manner in which our school children are taught during the few years they are permitted to attend school.

Probably it is not so much the method of teaching as it is the

curriculum of our public schools, with the fact staring us in the face that probably 90 per cent. of the whole of our school children must leave school before they are fifteen years of age to go out into the world to become our mechanics and tradesmen, as well as our small merchants that carry on the commerce of the world.

The question, I say, is whether our public-school curriculum should not be made to suit these conditions—whether many of the studies that really encumber instead of broadening the education of our youth should not be eliminated. In other words, why not confine the studies to the purely essential, leaving out, so far as possible, the ornamental portion of the education, or attempts at the full education of a lad who is to earn his own living after but six, or at most ten, years of his early schooling?

I know that, at times, attempts have been made to teach music, botany, astronomy, geology, physiology, German, French, object drawing or sketching, and various other attempts at the finer education, with the loss to the pupil of many hours of the really necessary course of grammar, commercial arithmetic, physics, and such mathematics as the average youth can attain in the few short years that he can attend school before being compelled to earn his own living.

It seems to be a generally recognized fact that the more mature periods of life are for rearranging or reshaping our store of knowledge, with a view to applying it in a new or striking manner, or of making judgments on the facts which are a part of our mental stock; and I think most of us will join in the belief of Mr. Higgins, which he holds in common with many educators, that a very young age is the most receptive. Now, when you take this natural fact or law of the mind's working in connection with the fact that, if not securing an education at an early age, the average poor boy, having to work hard for a living, will never have the same opportunity, how important it is to instil at that proper and only practicable period those essentials of education that are so much needed! Mr. Higgins appreciates this fact, and I am sure we all appreciate it.

Now, out of this large class come the youths who are to be our future mechanics and business men—whether the masters or the men—and if the parents of the small percentage of the remaining number are able to continue their boys at the high school, polytechnic, or college, let them pay the bills, and let the boys take their chances in the battle of life. We will find that they

will not always rise to the highest pinnacle of either work or fame; but the poor boy, with the essentials thoroughly grounded into him, if he has the natural bent, the push and the drive, will, by proper use of the little education he has, improve it, and often eventually push the better-educated, college-bred man out of the race, who has not had such practical training at the start. But the little education that the poor boy receives must be the essentials, and he must be thoroughly grounded in them.

I am sure it will please most of the members, who are typical men of some practical success in their profession—I think I may say this of the Society with appropriate modesty—please most of them, I say, to note how Mr. Higgins, a technical teacher, appreciates the practical and commercial side of the subject—the side which plays so important a part in the growth of a nation. He has no slight knowledge of business conditions, and shows his appreciation of how high technical training does not always insure success, commercially speaking.

I fear that I am not familiar enough with the operations of the Worcester school, and other schools where the system has been tried with success, to judge upon the figures he gives in connection with his proof by experience, or to judge upon the particular, concrete conclusions which he has deduced therefrom.

I fear also that I have not had time to go into detail in a way that one should to examine his theory adequately, yet my objections to his scheme, as a practical working one for all mechanical schools, may be set forth generally.

Mr. Higgins has not stated distinctly whether he intends his "Half-time School shop" to be that of a private corporation, or whether it is to be part of the public-school system. His figures show it to be a success in the Worcester school; but he does not state how much assistance the school has had financially, from endowment or otherwise, or whether it is a part of the public-school system of the grand old commonwealth of Massachusetts.

If the schools cannot be made the business of the State, I fear the possibility of their success from a commercial point of view, unless some philanthropist should endow such a school, to make up its deficiencies, and the school and shop manufacture some kind of standard machinery that could find ready and constant sale in a repository expressly for the purpose, or periodical auction sales of its product to the community.

From my view and knowledge of private concerns that are in

the business of manufacturing machinery of all kinds, very few of them care to be bothered with apprentices of any kind, and, in fact, some large manufactories make it a rule not to take apprentices at all; and I fear they would be carried off their feet if we should propose an apprentice system in which half the time of their lads was to be spent in school—either of their own or of the municipal providing. I do not believe this would be considered at all commercial; and it is commerce and the almighty dollar that move the people of the world.

I do not see how a commercial shop, as a successful attachment to or part of a technical school, is possible. The open market is certainly the final judge of excellence, so far as earning money for one's work is concerned, and competition is the life of trade. When all technical schools have commercial shops, these schools will have to follow the course of all commercial enterprises—succeed or fail. They cannot all succeed; and they that fail will bring the educational system of their schools to an end—at least the shop part of it. It seems to me there is no denying that a certain amount of schooling is more or less a preparation for, in a realm apart, than an integral part of, actual business life, and that the period of preparation is to a certain extent incompatible with the period of doing. Mr. Higgins bravely and earnestly seeks to unite them; but I doubt the complete practicability, the universal practicability of the uniting. However, I do not think Mr. Higgins's theories should be dismissed with a glance, but that they should be well thought over before a final judgment is made for or against them.

If the school workshops were made a municipal or State affair, I do not see how they could dispose of their output, or what that standard output should be. Surely, State schools would not be permitted to manufacture in competition with the commercial manufacturer. (I fear that the trade unions would be after us; they now govern to a considerable extent the number of apprentices that an employer may employ in proportion to the number of journeymen. This much to the disadvantage of the American youth, for, to my mind, it is a crime that an American youth should be deprived of the right to learn a trade by any labor union, and still have a free entry for the foreign mechanic to keep up the supply of our necessary skilled labor.)

The American youth are wards of the nation. The State does not hesitate to provide the ways and means for the higher educa-

tion of its youth till graduation from our high schools or free academies; and for this reason I do not see why the State should not supply, wherever possible, properly and thoroughly equipped school shops for its coming mechanics.

I do not mean the so-called manual-training schools, so many of which give our boys a smattering of everything that really amounts to nothing; for I have met a great number of them who came from the training schools perfectly helpless to earn a living at any useful trade, and who have had to start late in life to learn a trade with the common horde without education, and struggle on with the rest of their fellow apprentices. He is handicapped by age of a few years; if he is apt, his primary education may give him a few dollars more a week; but he is soured and discontented, and the manual-training school, instead of turning out an educated, trained mechanic, has turned out a hybrid that is neither scholar, mechanic, nor engineer.

I have no doubt that Mr. Higgins's contemplated system of vacation is a strictly proper one from the standpoint of theory, but again I think it too perfect for this imperfect world of action. It is generally conceded that too constant application defeats its object; and I think we all have had the personal experience of, after persistently studying a subject, becoming intellectually inert, and of, later, feeling our faculties refreshed after sleep or rest. On the other hand, continued idleness is just as injurious, and more so, to the powers of the mind.

We all, I am sure, appreciate the principle of variety, of change of scene; but, for all that, in this workaday world, who can take his recreation in accordance with an ideal plan? Who is able, I say, to choose his vacation? Competition will not permit it; the price of progress, of success, is dear. If we can snatch from our business hours a little holiday we are fortunate. Any elaborate system of interchange between work and vacation, in a real centre of business activity, seems to me, however desirable, too ideal to ever become a working fact. If the school shop is to be a commercial success, it has to follow the laws of commercial life.

Granting that such a system were possible in the school shop, the lad thus trained to a routine of alternate work and recreation would be seriously handicapped on entering the field of actual labor. He would find entirely new conditions that he would be unable to meet. His former training would render him unfit to stand, even if willing, the strain of continuous and concentrated

work. Untiring energy and aptitude for constant endeavor are, I may say, the chief requisites for practical success in the mechanical as well as in any other form of the business world.

The fact of the schools being a matter of the State, of course, is part of the political phase of the problem; but in touching on this side of the question I have not been unmindful of the extreme difficulty of its solution.

As I have said before, if the State pays for the higher education (many thoughtful persons consider it a crime to tax people for a higher education, which, in so many cases, proves utterly worthless in practical life), it should be willing to pay for the proper training of our mechanics. If thus given an opportunity for proper development, I am sure they would render a much better account of themselves than many of the youth of the land have with the "higher education." The higher education is beyond the majority of the masses; the practical essentials are within their reach.

As I said in the beginning, none of us would deny a citizen of the United States a higher or more thorough education; nor would any of us deny our machinists and mechanics the best possible chance to secure a sound common-school education and properly learn their trade. The greatest good for the greatest number is a profound ethical principle, and there is not a doubt that we all would see it carried out so far as technical and practical education helps the youth to make an honorable success of his life.

While I cannot see clearly how Mr. Higgins's system would be a universal, practical success, I think he may well be congratulated for the lofty as well as sensible views he holds upon the subject of technical training, and praised for his purpose to give the American youth a chance to secure an education and a trade as perfect and as wide as the liberal spirit and political system of our country will allow, stopping only at the limits of the individual capacity.

In conclusion, my views on technical education may be briefly stated. Ordinarily, the mathematical mind is considered to be the analytical mind; and for this reason I believe that the boy who shows an aptitude for mathematics is the best one to select for the mechanical engineer, foreman, or mechanic. Having made this selection, educate the lad in mathematics and physics as thoroughly as the age limit (say sixteen years) and his

necessity for earning a living will permit. Then apprentice him to the special trade or calling which he is to follow. At this stage his pay may not be great, but still it will be helpful; and at twenty-one years of age I believe he will turn out to be a well-rounded, educated mechanic who is prepared to do his share of the world's work.

All of this is within the possibilities of our public-school system, if properly applied.

If, on the other hand, the young man is to be a thoroughly scientific engineer, and his parents can afford it, then send him to the polytechnic school or college, and make the finished physicist, scientist, so far as possible, and therefore the thoroughly educated engineer.

And between the two classes I believe we can draw the line. The former, through early success in life, may have leisure to read and to study, by which, added to observation, he may attain to even greater distinction than the latter—though the chances are against him. The latter, if his practical training has been properly looked after, should make the fine showing that we might reasonably expect from his exceptional educational opportunities.

Prof. F. R. Hutton.—I desire to put myself on record as giving emphatic support to the underlying principles of Mr. Higgins's paper, and I base this contention upon what I consider to be lines of the trend of industrial matters in America. I would prefer to leave to others the discussion in detail of the methods proposed by Mr. Higgins, and confine myself to this line of thought.

I regard the position and function of the consulting engineer to be the outcome of conditions which have prevailed in earlier years in England and America, where the education and training required for the satisfactory solution of technical questions were limited to a few practitioners. When the municipality, or the corporation, or the individual desired to obtain a solution to an engineering problem they had to call in as adviser a consulting engineer, because they could not depend upon either the knowledge or the inclination—or, perhaps, even the integrity—of the contractor or producer of the desired article to give them what would be regarded, in the then state of the art, as a satisfactory solution. Such a consulting engineer was obviously in every case the adviser of the purchaser, and was to protect this latter against

being either misled or unsatisfactorily served by the producer or seller of the article to be supplied.

The present trend of industrial development in America is, I think, generally conceded to be towards an aggregation of capital and towards the economies which are the result of large units of output. Hence it has come about that the seller or producer of industrial material requires to have as his advisers persons having the same grade of ability as belonged to the consulting engineer under the elder condition. It may therefore result from this state of affairs that the engineer in the employ or in the interest of the seller or producer may know more about the problems to be met to the satisfaction of the buyer—who is the capitalist or the investor—than the consulting engineer, whom the latter would be expected to employ under the former status. This has resulted in the tendency for the buyer to enter less and less into detail in his specifications, but to ask more and more that the seller shall meet the guarantees as to problems which the buyer exacts. If the engineer of the seller or producer can offer standard products of theirs to meet given demands, the problem can be solved at less expense than where the consulting engineer, in the supposed interests of the buyer, imposes specifications or conditions differing slightly from the perfected standards of the seller; and this becomes worse when the consulting engineer yields to the temptation to impress himself upon his work by introducing departures which bear his own impress. It is this difference between the increasing American policy to which I refer, as compared with the older English method of the prominence of the buyer's engineer, which has given to America that notable achievement of the last few years, which has been evidenced in the American being able to meet and beat foreign competition in spite of the difference in labor charges.

Mr. Higgins refers most shrewdly to the principle which I have outlined herein when he says that if all the men concerned in production were educated men there would be no occasion for the consulting engineer type of person.

The technical education of the past and of the present in many places is directed to educate the consulting engineer type. The trend which I indicate is towards a diminishing field and opportunity for this sort of man, except in the employ of producers.

It is the reason for the tendency to narrow the field of what has been hitherto called the civil engineer, who is always the employee

of the buyer. We see this also in architecture, where the architect is becoming more the artist and elaborator of attractive façades; in the field of bridge-building, in the field of the steam-engine designer, the locomotive builder, and, in fact, everywhere. Hence it is small wonder that Mr. Higgins should have to refer to a disappointed group of men who do not find niches ready for them on graduation, and perhaps never will, from the fact that the number of such openings is diminishing and the number of men is increasing. In other words, there can be but one chief, or consulting, engineer for a corporation of normal size, while the demand is for a great number of persons having competence and calibre sufficient to serve in the various departments of production.

In this view I regard Mr. Higgins's paper, and its recognition of the principles which I uphold, to be one of the most important contributions which has been made for some time to the development and progress of America as an industrial people. It has been the custom, on the basis of the ideal imposed by the engineer as employee of the buyer, that it was of minor consequence whether or not he was expert along the lines imposed by successful production or construction. Our schools were based upon the competence of their students in the lines of mathematics and certain fields of their application, and a man who lacked mathematical or deductive capacity was thrown out into other lines of avocation, while it might easily happen that he was rarely endowed with the instincts and capacities of the constructor or adminstrator or the organizer. These are qualities belonging to the "producer side" of engineering, and are yet the qualities which have the greatest significance, if the community be viewed as an industrial one from the economic standpoint. This view has had its influence upon the speaker, as an educator, in providing that all students in his specialty shall be well grounded in what may be called "the business end of engineering."

What I would specially emphasize, in conclusion, is that Mr. Higgins's idea seems to be that of securing the training which is the best adapted for the many, and to give them the preference over a type of education which must be, if my economic principles are sound, useful to a few only of such persons as the modern community requires.

Prof. R. H. Thurston.—The "Education of Machinists, Foremen, and Mechanical Engineers" seems to me not one, but three,

topics; although but one seems contemplated in the paper. The professional training of engineers in the professional school, that of mechanics and foremen—who are simply the warranted men directing the rank and file and of the same material, though of selected quality—in the trade school, and that of training the hands and brains to work together, as a gymnastic exercise of great importance, seem to me radically different matters. Yet I have known distinguished members of the profession, equally distinguished professors in colleges and technical schools, and even highly distinguished presidents of institutions of learning who had not observed, and who could not see, even when pointed out to them, the difference between the manual-training school and the trade school, or between the latter and the college of engineering.

This distinction seems to me to be clear in this paper; unless, indeed, it may be charged that it is assumed that the trained machinist is, in virtue of that training, fully prepared to advance to the grade of mechanical engineer. I should say that a man most effectively trained in the most complete and perfectly planned trade school, without the higher training of the professional school, or its equivalent acquired by outside study and laboratory practice, which it may be admitted could possibly, though not probably, be secured, could hardly expect to compete with those men, thus trained, who have the power requisite to carry them to the front rank. The training of the machinist, further, for the purposes of the *engineer*, must be supplemented by that of the wood-worker and pattern-maker, of the moulder and founder, of the blacksmith, of the tool-dresser, and of the draughtsman and designer as well. All are requisite to the engineer.

The training in the trade school, properly organized and properly so called, is necessarily mainly, if not wholly, confined to a single vocation, as that of the mason, that of the carpenter, or that of the machinist. It does not involve advanced work in the pure sciences, with a view to their application in engineering works of magnitude, importance, or complication, nor the acquisition of a knowledge of the methods, and of technical skill in the methods, of the physical and mechanical and chemical laboratories; although, unquestionably, a knowledge of other trades is advantageous to the worker in either, and learning, scientific and other, and expertness and experience in scientific investigation would as certainly benefit every workingman were it practicable for him to acquire them. The demand for the trained and systematically

taught trades-worker is very great, in the sense that there is place and opportunity for millions where there is call for but hundreds of the class denominated professionals in engineering.

It is important, however, that the various classes and purposes of the schools and their pupils should be distinctly noted and understood. For the child growing up toward the period of youth and the beginnings of a working life manual training is as desirable as elementary instruction in "the three r's." To the young man seeking access to a working world a trade is imperatively needed, usually, and systematic instruction in the trade school is the ideal method of attaining skill and technical knowledge. To the youth seeing his way forward into a profession, no better route can be found, if naturally fitted for it, than through a well-organized school of engineering with its foundations solidly built upon general and scientific education, with a strictly professional supplement in the higher departments of constructive work. Each of these departments is a separate and markedly different branch of preparation for a special line of work in life.

In the best of modern engineering schools some practical knowledge is acquired, by the student, of not less than five trades—wood-working, blacksmithing, foundry work, the machinist's and the draughtsman's vocations—and, superposed upon these, the art of design and that of construction by utilization of all these trades at least. He is prepared to make himself, later, proficient in either trade, and in the all-embracing art of his profession. The product is truly professional, as truly as that of the school of medicine or law, and, as actually to-day brought out, involves a more severe training and higher attainments, scientific and general, than either of the older professions, so called, have been accustomed to demand.

The institution and the raising of standards in our country have been determined, usually, by circumstances, and have been dependent upon ability, on the part of the lower schools, to supply them. The raising of entrance requirements by our so-called schools of engineering has, in turn, been determined by circumstances in such manner as to settle the character of the school itself. We have every grade of technical school, from an inefficient manual-training or a trade school to a fairly satisfactory engineering college, and usually all under a common denomination. Classification is only now just coming to be scientific, and adapted to prescribed formulas for each class. A deliberately

planned system of technical schools does not yet exist; although it can be readily seen that it is soon to come in our States having State universities on broad bases, if not elsewhere.

The discarding of material and the oversupply of so-called "engineers" are a result of this lack of classification by established standards. There is, and can be, no oversupply of properly trained mechanics in any trade; nor is there, nor can there perhaps ever be, an oversupply of well-trained engineers. The overplus is that of inappropriately trained men. Germany suffers not at all from a surplus of educated technical graduates, but from inappropriate training of the men graduating. In that country the trouble arises from the fact that those wandering candidates for employment have not been given preparation for immediate usefulness. There is, to-day at least, no such difficulty with the American graduates, as a rule, even when coming from the largest schools, simply because they have been given a practical as well as scientific training, and have been taught to unite in a practically useful degree the two essential elements of success—scientific knowledge and a practical use of science in the arts. Individual failures, undoubtedly occurring, are due to this defect in the individual, or often to the fact that the individual is not gifted by nature with the qualities which confer power of compelling success in the particular and wrongly chosen profession in the individual case.

The proper solution of the problem is not the abandonment of either the trade school or the school of engineering, nor is it their intermixture, but the guidance of the right man into the right career: many into trade schools—trade schools which should be provided for the thousands—and others into schools of engineering, which are already provided for the hundreds. Both institutions should be provided with shops, each of a suitable kind.

The paper under discussion considers the form to be given the school for machinists, which, obviously, is a different matter from that of the engineering school or college.

The Worcester school of 1870–1896 has proved itself one of great value and extraordinarily successful—so much so, in fact, that it may perhaps be fairly questioned whether that success could ever have been attained except for the good fortune of securing from the start that remarkable, that unique individuality in its management which lies at the foundation of its efficiency. I have

watched this school with the greatest interest from its inception, and have, during the quarter-century of its existence, visited it and studied its operation with as great frequency as opportunity allowed. The history of its operations given by its superintendent is, in my opinion, one of extreme interest and value, both historically and as illustrating *one* admirable method of technical instruction. The plan to which its management has been led by this experience, as presented in the paper, seems to me entirely practicable and likely to prove, if well carried out, a most efficient system. Its operation will necessitate, as a matter of course, the adjustment of all instruction methods and time-distribution to the exacting requirements of the shop. It is the system, however, of a trade school, and not of a professional engineering school. The points of contact and of common interest for both schools are well summarized in the course of the discussion.

It is as true of the school of engineering as of the trade school that the instruction, even in the teaching of mathematics and the sciences, pure and applied, should be given, as far as practicable, by men familiar with the practical work to which it leads. A knowledge of the forms and action of the tools of a trade, whether hammer and chisel or mathematics and physics, cannot be acceptably taught alone; their actual *use*, and in all their applications in the business, to be well taught, must be exhibited and illustrated, and by the expert practitioner familiar with those scientific bases of technical instruction. The amateur has no proper place in a technical school in any one of its divisions. The work cannot be made too practical.

The real question to be solved is: How is it possible to secure the maximum degree of practical usefulness? In the solution of this question the experience of the Worcester school shop must prove of the highest value. It is certainly possible, in such a school and shop, to secure higher proficiency in the details of the trade-work than in any properly organized engineering school, simply because time is given more completely to a comparatively circumscribed work. The plan outlined would, I have no doubt, prove entirely successful, admitting, as a matter of course, that experience will more or less modify such of the details as may prove capable of further improvement.

The record of the Worcester school, not only in its own work, but in that performed by its graduates, is an admirable one, and the country is largely indebted to it through the efficiency of the

men who have been trained in its twenty-eight years of work in the form described. Its financial history is perhaps the most remarkable and gratifying of all the details here so fully exposed.

I have taken the trouble to obtain advance proofs of this paper and to distribute them among the interested members of the Sibley College instructing staff. Some of the various views made in reply to my suggestion that each present his impressions are exhibited in the following pages:

In opposition to the proposed plan we have this comment by one head of an important department, who has passed into the profession through the usual scholastic and technical college channels:

"I have read the paper of Professor Higgins, and disagree with him as to conclusions from practically every standpoint. In the first place I believe that the present method of educating trained mechanics by apprentice courses in actual shops is better than the one he proposes. His plans, in my opinion, are thoroughly impracticable, and I believe, if carried out, would not give any improvement over present methods. That American mechanics are well trained is proved by the superiority of American shop products.

"In my opinion the object of a shop course in a technical school is to impart knowledge rather than skill, and I believe a great mistake would be made if commercial methods were introduced."

It does not seem to me, however, that the plan is to be condemned as impracticable, for it has certainly proved itself capable of a great work. Constant contact with skilled workingmen, intelligent as they always are, is most inspiring to a bright and wholesome, ambitious boy, and he will certainly improve greatly under such influence, in all ways. The whole story and its author's arguments tend strongly, as it seems to me, toward the demonstration of the practicability and desirability of the adoption of something of this plan into *every* business and shop; and I have an idea that its most valuable and extensive applications will in time be seen in that direction. The comments upon the need of improved draughtsmanship are well founded. It is, I think, the experience of every one having anything to do with the conduct of our technical schools of whatever grade that a principal problem is that of securing good workmanship in the departments of drawing and machine design in the limited time there obtainable for simple practice. In some cases not a single finished drawing is

made from the beginning to the end of the course, and the refinements of draughtsmanship are usually unknown. This may, however, be better than the common European method, which appropriates an excessive amount of time to finish work to the exclusion of original design and varied work.

The paper is full of good suggestions for every class and grade of technical instruction. That regarding lengthened working periods touches an important problem. With us it has in a way solved itself. Ambitious students give their vacations to shop work in large numbers, sometimes to get it out of the way in order that they may take on additional work in other departments; often that they may be able to secure a more extended practice in construction, in engine-building, lathe-making, etc. During this last summer we had about a hundred students working in the various workshops of Sibley College.

An officer of the college, who has had some considerable experience in a variety of technical schools and who is himself a graduate of a famous special school, the Naval Academy, familiar in all its details with the Worcester school and its work through several years of observation close at hand, Professor Durand, says:

"To many the most interesting features of the paper will be found in those portions dealing with the history of the shops of the Worcester Polytechnic Institute during the years they were under the charge of Professor Higgins.

"In June, 1887, I had the pleasure of serving a short term of duty as a teacher in that institution, and, without injustice to the other departments, I may say that I was especially impressed with the work of the shops. Their organization and conduct on a business basis, and the manufacture of articles for the trade in open competition with commercial establishments, gave the shops an atmosphere decidedly different from that in other college shops with which I have been familiar.

"The Worcester graduates have borne an exceptionally high reputation for excellence in practical shop training, and it is but just to say that they owe this to the possibilities permitted by the excellent shop equipment and by the practical business atmosphere with which they were surrounded in this part of their course. It is, furthermore, only just to add that this atmosphere, and perhaps in a large degree the possibility of successfully conducting the shops on a business basis, were due to the good judgment and the pervading personality of the superintendent.

"The Worcester shops stood for a quarter of a century as a working demonstration that, with a suitable administration and with the proper personality at the helm, shops for collegiate instruction in the mechanic arts could be satisfactorily conducted on a sound business basis. Whether or not such basis is the preferable one, and whatever may be the ultimate form in which the subject of manual training is to be worked out, both for the training of engineers and for that of mechanics, the work of Professor Higgins at the Worcester Polytechnic Institute will aways stand as one of the most interesting and valuable of demonstrations of the practicability of one solution of this many-sided problem."

Prof. G. H. Shepard, U. S. N., also a graduate of the Naval Academy, and now engaged in the Department of Machine Design in Sibley College, a gentleman of considerable practical experience in various fields of work, has the following to say of the Worcester plan:

"It appears to me that the author attaches undue importance to the machinist. In my own experience I have found it necessary to lay out, direct, inspect, and oversee the work of men of the following trades: Draughtsman's, machinist's, boilermaker's, blacksmith's, moulder's, coppersmith's, pattern-maker's, stoker's or fireman's.

"Of these I should attach only a slightly greater importance to the machinist's trade than to the draughtsman's, boilermaker's, blacksmith's, moulder's, or pattern-maker's.

"I submit that it is impossible for the mechanical engineer to be a thorough workman in all these trades, and also that every scrap of knowledge, practical or theoretical, and all possible mechanical or manual skill that he can obtain in any of them, are of the utmost value to him. The requirements are conflicting. There is an immense amount to learn, and even a lifetime is too short a time to learn it all.

"The solution is to be found, in my opinion, in the engineer's common sense, and in his keeping his mind in an attitude of receptiveness. He should never forget that his mechanics will probably always be able to teach him the details of their own work. He should always receive their suggestions attentively, weigh them carefully, and, when convinced of their value, adopt them.

"I submit that the engineer who has served his time as a machinist has no advantage over the engineer who, with less knowl-

edge of the machinist's trade, combines more knowledge of the other engineering trades.

"Putting aside the enormous difficulties in the way of making dividends from an instruction shop, is a commercial shop best adapted to instruct? To put this question in the clearest light to ourselves, I will put it this way: Would it be advisable to try to realize dividends from the shops of Sibley College? Would not such an attempt injure their ability to give that instruction which is the reason of their being? The answer is a matter of judgment. In my judgment the attempt would not be advisable. Certainly the teaching staff of an instruction shop should make every effort to teach the quickest, best, and most practical methods, and the question of cost should always be emphasized to the student; but that is a different matter from making the shop itself pay dividends.

"It seems to me that both the faculty and the students of Sibley College have largely solved this problem for themselves by so largely spending their vacations at work in commercial shops—shops that must pay or quit.

"As for the writer's idea of sifting out from the whole country those men who are best fitted for the engineering trades and professions and bringing in those men and no others, I consider it Utopian."

Prof. D. S. Kimball, of the same department, who has had an extensive college and business experience in important departments of mechanical engineering, makes the following comments:

Page 1.—"I do not believe that the *manual skill* required of the machinist is as high as that of thirty years ago. While some of the machines we now build are more COMPLICATED than any of that period, the tools furnished the workman are vastly superior to those in use at that time, so that the various portions of a complicated and delicate machine can be made more cheaply and easily and with less skill of the operator.

"For the same reason we have nearly obtained control of the world's markets. It is not so much the good management of our shops that has enabled us to do this, but it is the result of our great advance in machine-tool construction whereby a man of little skill can turn out fine work in great quantities (turret tools, for example)."

Page 3.—"It should not be necessary for an engineer to be *able to actually do* all the processes in a shop. In fact, it is im-

possible for him to learn to do all these processes. But he should know as much as possible about shop processes in order to design in a knowing manner."

Page 4.—"I do not think that the remarks about European polytechnic graduates overstocking the market applies to American schools. At least, the experience of Sibley and other high-grade colleges does not *appear to bear out* the conclusions drawn."

Page 6.—"The school outlined is, I take it, one in which students shall receive more practical training somewhat at the expense of the time now devoted to theoretical study. The standard is to be the same as the high school at present. No doubt it would reduce the number of students who are out of place in engineering colleges if such colleges drew their students from them entirely. I doubt, however, if they would be able to qualify themselves in four years of such a course for entrance to technical colleges with the present standard of entrance requirements. Not only will they have much less time, but such a system would, it seems to me, interfere greatly with regular theoretical instruction. So that, on the whole, a student who finishes the high school and then spends a year or so in a machine shop would, in my opinion, be better fitted for entrance to a technical college than a graduate of the Half-time School, abilities being the same. As to the self-sustaining portion of the scheme, I believe it would largely depend on the man at the head of the establishment. Under proper management, no doubt, such a school can be made to pay. And students would get much more out of work on a commercial basis than they do out of the other or 'exercise system.'"

Professor Ryan, in charge of electrical engineering in Sibley College, and a graduate of this institution, of business experience as well, says:

"I have read Mr. Higgins's paper carefully, and I find that I agree so completely with the central thought of the paper, that it is difficult for me to criticise it in a manner that does my own ideas credit.

"I believe thoroughly in that system of education which begins by acquainting the child with all essential characteristic facts relating to nature, social customs, human industry, material and moral progress toward happiness, and the duties of citizenship, and which supplements this with a start in the acquirement of the details of a specialty of the child's own choosing; every

effort being made to have the young person comprehend that it is only by continual thought and intellectual effort directly applied to one's special calling, and indirectly as it touches other departments of human interest, that actual success will surely be obtained. I believe that the secondary schools should do more in nature study, and every child should be given a course of study by which it would acquire knowledge of the chief characteristics of industrial life.

"The way to bring humanity out from under the yoke of materialism is to make sure of the industrial necessities, to begin with; all surplus energies will then be directed toward the higher interests and attainments of man. No person who has once taken hold of the industrial sense fairly in early life will flag in his interest in human welfare. Those who have found, by long years of cunning and miserly privation, ways for coming to material gain, often retain the effects of early disappointment and industrial strain, but do not cause an exception to the above. The spendthrift, indolent and criminal individuals come from the classes who never secured fairly an industrial hold.

"Mr. Higgins argues that the training of mechanical engineers as now ordinarily given in the technical institutions is enormously wasteful. He claims that, 'In a class of 100 in an engineering college, if only five make engineers such as the course is aimed to produce, the 95 others have not, in all probability, received a course of training well fitted for their special needs and capacities. Further than this, the large portion of the class who are, to some extent, failures, are also frequently disappointed men.

"'There are many reasons why the young man who enters an engineering school is allowed to get false ideas regarding his future. He understands that there is a lively demand in the active world for technically trained young men. He likes the idea of being an "engineer," and he knows that all the leading technical schools have high-grade engineering courses, the requirements are up to the colleges, and he expects when he graduates he will be able to engage in engineering work. When he finds that he either cannot do engineering work at all, or that there are ten engineer graduates to one position of that particular kind, and that every year the demand for professional engineers grows less and the graduates more numerous, he turns his attention reluctantly to a lower grade of work, and is never quite satisfied or happy in it. He feels that he was born and educated for

something better. But was he? No; he only thought he was. His failure would be no fault of the school, however, if he had not been, in a sense, educated away from the work that he is obliged to undertake. These "culls" from an engineering class are not first-class material for workmen in any department below the engineer. Such a man is a disappointment to himself and to his employer. And though we may be able to show that every graduate in a class has been greatly benefited and developed during the course of study, yet that is not a sufficient reason for a course fitted only to the very few, and which allows the large majority to come to their disappointment through the general understanding that, if they were graduated, they would be engineers *because* they were graduates.

"'Consider, also, what a fearfully expensive system this is, with its large percentage of failures, or partial failures, to educate the few, of which there is already a larger number than can secure positions.'

"A great deal is to be said about the points brought up in these paragraphs. There are, doubtless, technical colleges to which this applies. It certainly does not apply to Sibley College. In my own experience I have come across no more than six young men who exhibited this disappointment. 'He feels that he was born and educated for something better. But was he? No; he only thought he was.' Without exception they were young men who impressed me as likely never to have been happy under any system of industry and education. They had never realized the fact that no process of incubation can hatch them into a realm where human competition does not exist, and where the individual no longer needs to earn his own independence. Even if but 5 per cent. of our young men are, by talent and opportunity, elected to become engineers of reputable standing, the remaining 95 per cent. have an excellent training with which to enter any department of industrial life. A member of the class in electrical engineering called a few months ago at my office. He was entirely happy with his experience since graduation. He had been employed almost entirely as an agent in the British Isles for a Michigan furniture firm. He felt that his Sibley College training and association at Cornell had assisted him to become a man able to enter successfully numerous lines of industry other than the particular one which he had selected as a calling at the time of entering college.

"It seems to me that the Worcester plan is a good one so far as it goes. I cannot see that it is likely to have a very broad application, for the reason that superintendents and managers can never be found at moderate salaries who are needed to make it a success. The business, executive, and technical talent necessary to manage successfully the *construction-instruction shop* will find better pay or greater profits in non-instructional commercial enterprises. It is argued that the instructional-manufacturing plant will pay, because what is lost from profit by instruction will more than be gained through the fact that the student gives his labor in exchange for the instruction. In our nation I think this may be so to a small extent, or when carried out on a small scale. I think it is a plan that must fail utterly to reach the masses of mechanics, because on a large scale competition with ordinary manufacturing production would cause so great a deficit as to make it impossible to supply the same from endowment income. Mr. Higgins seems to think that where the engineering college fails to reach the poor boy his Half-time School would. He seems to lose track of the fact that his half-time boy is under the expense of living and producing nothing while at the Half-time School, just the same as the engineering student, except that the engineering student generally pays for his tuition, while the manufacturing student earns his tuition.

"I cannot possibly admit the point that the manufacturing-instruction plant will be a live and up-to-date shop in what it turns out and the methods by which its products are produced, simply because its existence depends upon earning a profit which shall defray expenses of instruction. Except under managements most difficult to secure, articles will be manufactured where the labor item is ordinarily the greatest and, therefore, the one where the no-cost-instructed labor will bring the greatest return. It is not clear to me, then, that the young machinist will secure as valuable a training by this system as by the system in which instruction and wage-earning are entirely distinct. The factory cannot be a laboratory for instruction purposes on any considerable scale, for the reason that most operations are carried on in such a way that it is difficult to bring to light and to emphasize fundamental principles. It is the business of technical education to train young men to get at the underlying principles of any line of industry with which they have to deal. It is this which at once marks the difference between the engineering-trained young

man and a man who completed his trade as a machinist. To the first each new experience enables him better to look ahead to plan and direct work or men, because he has been trained to deduce the principles of operation from the facts before him, while the second, with his apprentice training, can find only one more item of experience added to his skill by which he may the better do what he is told.

"Of necessity there are many men better suited to follow than to lead, but to lead a man must be able to design, foresee, predetermine, or prearrange the work of others, to do which he must work by principles, not by rule of thumb. Mr. Higgins is right in claiming that there are many in the rank and file of machinists who are born leaders, but poor. He admits that a man who is not a leader is better off with an engineering education than without one, regardless of his station. His argument is that it would be better, however, not to waste so much substance on 95 men who can afford the engineer-college course for the sake of discovering and enormously aiding the five leaders from among every 100 of this class, and that it would be better to apply such funds in a more equitable manner—by a system in which the 5 per cent. from the rank and file would be discovered and enormously bettered and the remaining 95 per cent. indifferently bettered. I think this would be better if it would work out that way. But it cannot work out that way. The rank and file of boys who are to become machinists are not much nearer in reach to Mr. Higgins's system than they are to a Sibley College course. It follows, then, that his system is applicable particularly to those cases that can afford it, but cannot afford the college engineering course. There are, therefore, more of the rank and file of the poor boys who are going to become machinists that are not aided by either plan. And it is fully admitted that industrial standing is best, and I think the condition of the nation best, when the industrial training of the rank and file will have been made the best. To get the result Mr. Higgins has in mind, a sensible and practical primary education should be given every child as stated above. Ample object lessons should be given in the schools by which the child is impressed with the benefits that will come from study put primarily upon one's daily calling, and secondarily upon the affairs of the community and the nation. Then let the poor child, whenever necessity demands, go to work with the advice that such work be selected as fits its natural talents best, the child decid-

ing, which brings in the most pay and hours for needful recreation and self-improvement. As time goes on the boy will find a demand for further training. Since the boy is poor he must rely at present upon such tutoring, night school, or correspondence instruction as he can afford, or he must save his money until he can stop work for a time and go to school again or to college. And thus there is no end to the height to which the poorest boy may climb. However, I do not believe in forcing this process. I believe that all young people should at all times be taught to make the best of their own situation as they find it. A fault I have to find with Mr. Higgins's system is that he is too optimistic as to what may be done by observing the boy at school, and developing his capabilities by applying a suitable prescription. Far better give the boy an early idea of the practical characteristics of society and industry, and let his own tastes guide him according to his actual opportunities, and let the government or individuals or both provide facilities that shall always be open in every practicable way to the man of defective early training whereby he may be bettered industrially and socially. I have no idea that Mr. Higgins's system could ever be a great factor socially. I fail to see how a manufacturing plant in general can be made a satisfactory germinating ground for the essential and desirable social characteristics. The composite and distracting nature of factory tactics is such as to make it a very difficult matter to bring to light in the boy's or young man's understanding the inherent value of politeness, affability, absence of peevishness, appreciation of another's point of view, manliness, and wholesome and agreeable self-respect.

"My conclusion with reference to Mr. Higgins's system is that it has a useful place in supplying a limited demand for industrial or technical training. What Mr. Higgins apparently hopes to effect by his system is to be accomplished better by existing systems of primary education, which should be improved by the nation's best talent and be made compulsory to a reasonable degree. The best talent should also be secured by private endowment and government assistance to instruct the man who, as a wage-earner, wants to progress by intellect and self-help. Defects in early training should embarrass a man in subsequent efforts to secure industrial and social education no more than necessity demands. At the present time I am convinced that improvement in social character is to be looked for in primary education and

that kind of education which will eventually do so much for humanity, and which is now carried on in night schools and by correspondence. As above stated, the training factory can do little in this important matter either way."

The head of the Department of Mechanic Arts, Professor Morris, who is a Union College man whose collegiate education (A.M. and Phi Beta Kappa) was supplemented by a long apprenticeship and business experience in the railroad repair shop, on the rail, and in various manufacturing and engineering departments, and who for twenty-five years has been engaged in directing a college shop, says:

"We are so prone to judge of matters in the light of our own experience, that I, having served an apprenticeship at carpentry and as a machinist, also having had a small shop of my own, where I was obliged to do moulding and often forge work, view with considerable doubt the plan suggested by Mr. Higgins.

"I do not believe that Sibley College, or any other school in the country, can turn out at the end of a four years' course just such men as Mr. Higgins wants, but I do know that we are graduating men well fitted, who, after a few years' experience, can become foremen or superintendents and do well.

"As for 'the amount of discarded material,' do we not see it in theological, medical, law—in fact, in all schools?

"No four years in any Half-time School can make even a good machinist. The time is far too short."

The foreman of the machine shop, Mr. Wiseman, who is a mechanic, a business man, and an engineer of many years' experience, states as his opinion:

"The paper of Mr. Higgins has been carefully read by me, and while I have no doubt that such a school as he advocates will reach a certain class of boys, I cannot agree with him that such a school-training as he lays down can ever take the place of the real apprenticeship system. There is no teaching like that which passes from hand to hand, from eye to eye, while practice illustrates what is inculcated by precept. And in all the arts there is something which is of highest value, which is gained by absorption in the very atmosphere of the workshop of a master workman in his craft, who himself acquired his skill amid similar surroundings.

"There are traditions in all arts which do not take form in words."

His senior assistant, a gentleman of wide practical experience as a skilled machinist and as foreman, who has now had some ex-

perience also in college-shop instruction, remarks, on the other hand:

"The paper is, in my opinion, very ably thought out and written, and shows by the manner in which it is gotten up and the common-sense way in which every branch of its subject is treated that he knows whereof he speaks. I think that if these schools were placed in different parts of the country the result would be a higher class of mechanics turned out than can be by the present system of apprenticeship. All business is now done under such high pressure and with such fierce competition that almost everything is sacrificed to economy of production, and the apprentice does not get the time and attention that he needs.

"I think the advantage of working with the skilled mechanics would be very great, as the student would be thrown daily into contact with practical men, and they would learn to do their work in a practical way. In this the nail is hit equally on the head on page 13, where the unfair way in which boys are chosen for engineering schools is referred to. They are prepared for examination by cramming studies selected for the mere purpose of excelling in entering college; while, in a school of this kind, they are selected because, on inquiry and observation, they are shown to have that in them which, if developed, will make a mechanic.

"Vacations would be a matter to be handled carefully; but the furlough system might be made to fill the bill."

The foreman of the blacksmith shop, Mr. Granger, who is an experienced mechanic, who has seen practically every form of work assumed in his department and every variety of practice in all sections of the country in the course of a long business life, and who has now had some years of successful experience in teaching students in a school shop and with rare success, states:

"Give a boy a first-class education in a technical school and then let him serve an apprenticeship in some special line of work. It takes half a lifetime to make a foreman. Time is too short in any technical school, and the graduate is too young to reach that dignity."

The foreman of the foundry, also a man of extensive practical experience supplemented by years of work in the school shop, says:

"It requires natural ability and a long experience in different shops at various kinds of work in the same trade to make foremen."

Collecting all these various ideas, it becomes very evident that here, as in almost every other department of life, there are various ways of doing things, each of which will find its particular place and do its special work in its own way best for its purposes. The thought that is impressed most strongly on my own mind is that this is perhaps a very important suggestion for the consideration of manufacturers and shop foremen and superintendents and managers.

It may perhaps lead to the adoption of some such plan not only in a very important class of school shops, but, and more important, in manufacturing establishments in which the apprenticeship system of the older day is drifting out. Why cannot this scheme in a suitably modified form—and perhaps not very greatly modified—be employed in every workshop in the country in which public spirit and a sense of the obligations which every man owes to the coming generations are found together with the common business instinct which teaches every successful business man to deal in all kindness and very liberally with every class with which he is brought into contact? I am still investigating the question and discussing its practicability with this class of men; but I see no reason yet to feel the slightest doubt that it will prove, if attempted, perfectly practicable to effect a combination between the shops and the public high schools in such manner as to secure this admirable combination of the academic and the systematic technical training of young boys—and girls perhaps—in advance of their entrance upon the purely selfish stage of trade and business life. This is certainly a matter worthy of thought and investigation.

Concluding this comment, and this compilation of opinions presented by the officers of a single, and therefore, it may fairly be admitted, not absolutely unbiassed, body of professional technical instructors, it may be added that probably the difficulty which presents itself to a responsible body of trustees, and a faculty inclined to adopt the methods here so clearly and fully exposed, will be found to be, in the main, the twofold uncertainty of finding capital and holding it secure, and of insuring the appointment, if they can be discovered at the time at all, of men as competent for their work as Professor Higgins proved himself to be for his great and splendidly completed task.

The collecting of capital and the making sure that it will not be lost through the usual method of closing up of a manufacturing

enterprise—ultimate bankruptcy—as a consequence of the sooner or later very certain maladministration of the business, or of the fluctuations of the market and the business of the country, will usually make any board of trustees hesitate. Risks due to the employment of men without the real genius which is needed to make any business successful are here vastly greater than with the ordinary school shop, conducted primarily for instruction, and without incurring the risks of a commercial enterprise. I have myself been asked whether I was willing to assume these risks, and must confess that I have declined to take any share of responsibility. To the making of articles, as time and opportunity permit, in an "instruction shop" there can be no objection. It involves no risk, and allows of the adjustment of the workings of the whole establishment to its primary purpose, while giving something of the advantage of the so-called "construction shop."

The "instruction shop," independent of the market and of the necessity of considering anything else than the immediate purpose of its establishment, has some decided advantages. It lacks in some degree—not altogether—the commercial atmosphere of the business establishment; but it may possess the more essential aspect and spirit of a good manufacturing shop engaged in "real, full-grown work." It is entirely free from the trammels of a business which compels the making of a certain marketable product and nothing but a marketable product. Its manager is freed from the anxieties of a minor business, while he should have head and heart entirely free for the major work of making good workmen. The student can be given maximum attention and trained by systematic method, presenting him the simplest task first, a more difficult one next, and thus gradually leading on to the most skill-commanding tasks, and without being hampered by the necessity of keeping him employed in a certain restricted line of work, once he has acquired skill, in order that he may make a profitable job for the selling part of the business. In the "instruction shop" he is given a new exercise immediately he has acquired sufficient skill in the easier one preceding on the schedule; while, in the "construction shop," he must be first taught skill, and only then can be allowed to work on a commercial job; utilizing time that should be given to his further instruction, and for his own benefit, instead of for that of a business. The limited amount of time obtainable in a good school of engineering, in my opinion, can be vastly better utilized, for the advantage of the student, in a course

in which instruction is the primary and controlling consideration than where time must be thus lost by the student—after skill has been acquired—to meet the demands of a business. The wonderful efficiency of the "instruction shop," conducted with proper system and with a carefully worked-out sequence of exercises leading up to the final perfection of the art taught, cannot be understood or appreciated until one has seen a student made a fairly good wood-worker in the equivalent of a month or six weeks' work, another made competent to do any ordinary work of the small foundry in still less time, and, in the blacksmith shop, given sufficient skill in iron and steel working to be able to make his own tools for use in the machine shop, *and to temper them well*—producing a dozen or fifteen lathe and planer and bench tools, such as any old hand would be glad to get—in the equivalent of less than a month of the working time of a shop. Similarly, the equivalent of two months' work in the machine shop may thus be made to give the young man having a natural gift for the business—and none other should enter or remain in it—the power of using every tool, and of doing any form of work that any working drawing coming into the shop may demand of him. He can attack with confidence any job that may be called for, whether the routine work of a commercial business or other; and none of his time has been lost in the effort to secure a profit on a routine product. The question now is: Shall he next proceed to further advances, or give time to a business?

The "instruction shop" is not confined to a certain line of production; which narrow system is necessary to the success of any commercial production, school shop or other. The product sought to be made may be that which will best bring out skill and adaptability on the part of the young workman. In our own shops we have built wood-turning lathes for the carpenter and pattern shops, speed lathes and engine lathes for the machine shops, steam engines for the electric-lighting department, experimental apparatus for the mechanical laboratory, models for the departments of instruction, and our "underwriters' fire-pump"; taking up one or another piece of work as the foreman of the shop finds time and opportunity to utilize acquired skill, or nearly attained "passing" skill, in varied and useful work, selected with a view to the advantage of the student, not to that of a perhaps critical business situation. Monotony of production is the essential feature of a profitable constructing business; variety of work is an essential

element of school instruction, especially in the engineering as distinguished from the trade school.

Experience with the "instruction shop" leads me to conclude that, in an engineering school, at least, no time can be spared to manufacturing for a market if the school is to be given maximum efficiency, and the embarrassments of a business cannot, without sacrifice of the student's time and highest educational interests, be safely assumed. With all that is now demanded of the young engineer, and with his time of professional study restricted to four years in college, and often with incomplete preparation, it will be found best, in most cases, at least, to lose no time in applying skill, once acquired, to the commercial work of producing for a market, even where the authorities can find the capital, and will accept the risks of a business enterprise conducted by men whose first business is to teach the student maximum skill in a minimum time. Were there no other consideration, the level-headed men of affairs, who usually constitute such enterprises, recognizing the fact that the good teacher is, as a rule, not the best business man, will not take the chances of ultimate loss of capital and a breakdown of the whole business through the almost absolute certainty of, sooner or later, the failure of the management to prove itself more competent than the ninety-odd per cent. of business men, pure and simple, who fail out of nearly every business in the end.

It being shown that the proposed system is practicable and safe in operation, it would be interesting to see it adopted by business men in such form as will make every manufacturing establishment a school for its own apprentices, and thus to supplement the institutions of learning in which technical schools are included by a broader and more directly useful system of educating the youth of the country at large in industrial operations.

Notwithstanding all this, I could not deny, even if I would, the magnificent success of the Washburn shops, in which good instruction and successful business have been brought together by the rare genius of a man precisely fitted to conduct them. Given the man and the capital, the "construction shop," as this experience has shown, may do a noble work.

Submitting the paper to the chairman of the city Board of Education, and asking an opinion on the practicability of uniting the high school and the machine shops of the place in such a scheme for the education of apprentices and apprenticeship of students, the following is received:

"I think the plan theoretically most desirable, but practically subject to serious objections. In the conduct of the public schools it is necessary to cater to a certain extent to the sentiment of the tax-payers, and they, as you know, are in many ways, as a body, poorly informed, sensitive, and critical. While public sentiment is more and more strongly favoring in a general sense such systems of secondary school education as lead to an early preparedness for self-support, local selfishness and local jealousies oppose the fostering of technical education in any one industrial branch to the exclusion of others, and local possibilities make it out of the question to establish here manual-training schools of sufficient breadth to cover the entire field. It seems to me that Mr. Higgins's plan might be successfully carried out in large cities or large industrial centres where the municipality was clearly dependent upon manufactories in the lines indicated, but I doubt its feasibility in little Ithaca or in any small town. Another difficulty occurs to me as possible even in the large manufacturing town: the jealousy of a commercial competition founded and supported to a certain extent at public expense. An independent, endowed school entirely separate from the public-school system would not be subject to these objections, and, conducted upon the lines suggested, would be a public blessing."

Mr. H. S. Haines.—I have read this paper with interest, because it invites confidence in its author's familiarity with the subject and in his earnest purpose. There is much in it to admire, and a disposition to criticise it, here and there, is tempered by a doubt lest the author's evidently superior knowledge and experience should, in rejoinder, disclose the critic's ignorance. It is with this doubt overshadowing me that I venture to discuss the paper, rather to elicit further information than to question the author's facts or arguments.

Now that the manufacturers of this country are entering into the markets of the world, they everywhere meet with competitors whose wares are the handiwork of cheaper labor. Yet they are expected to maintain themselves in this contest and still pay higher wages than are paid by these competitors. Unless they can get a greater expenditure of muscle for their money they must make the difference of wages good by getting a higher order of intelligence applied to their work and to its resulting products. They must get more brain if they can get no more brawn. If this be a fair statement of the situation which our manu-

The practical question involved in a discussion of this paper may be presented in different aspects, according as we view the interest of the employer or of the employee. The employer must turn out the best article for the least money to hold supremacy in the market. Where American employers have secured such supremacy it has been by the control of abundant and cheap raw material or by the use of special machines tended by unskilled labor. This is probably true of the greater part of our exported manufactures. Success has not been so much due to the manual training of the mechanic as to the brain-work of the engineer. The former can unquestionably be acquired in each line of business in the shops where the processes of production are greatly specialized, and therefore much better than in a shop for general manual training. The development of the designing engineer is but partly the work of the schools. As the author recognizes, there must be natural ability, a special adaptability of intelligence. But while original ability is essential, such ability must be developed by intellectual training rather than by inspiration during hours of manual labor.

So far as the author has elaborated his project of a Half-time School, it might be established in connection with certain industries to the profit of employer and employee; but that all mechanical engineers would be better equipped for their specialties by a course of four years in such a school is not clearly established.

At the same time, the author's objection to technical schools, as now constituted, calls for an investigation of their methods, with a view to adapting them more closely to the prospective requirements of industrial progress; if, as he says, the existing method of training is fearfully expensive, with a large percentage of failures, while but few of its successes can secure positions. The value of culture is not overrated by the author. It is a matter on which stress should be laid by all who seek to elevate the human character in any walk in life. It is not beyond the reach of the humblest who can read and write. It does not come by excellence in manual dexterity, but in intellectual development; not by the acquisition of facts, but by assimilation of ideas, of noble thoughts and of courteous acts. Therefore it is that culture comes by association with cultivated persons and by reading the works of those great men who have handed down the torch of enlightenment through the ages. And we, in our generation,

should be careful not to lose sight of this important element in the making up of a human being in our desire to produce the best article for the least money.

Prof. John E. Sweet.—I am led to comment upon and supplement Mr. Higgins's paper, which to me has been as fascinating to read as a romance, because I believe it contemplates and proposes a move in the right direction.

Professor Kennedy, of London, who was at one time one of a leading trio of instructors in mechanical engineering, made the remark, after he had been in active engineering practice for three or four years, in effect that he would be from his few years' practical experience a very much better instructor.

Mr. Higgins, with his twenty-six years of experience in the management of the Washburn shops of the Worcester Polytechnic Institute, now, after three or four years of outside work, is so firmly convinced that they were on the right track, that he comes forward with a developed plan carrying the ruling idea of the Worcester school (that which was looked upon by some other technical schools as being carried too far—*the commercial end of the school shop*) still further. Whether it was or not, under Mr. Higgins's management, the best school in the country, the Worcester school did that which no other did, so far as I know: published results—not how many graduates they had turned out, but what the graduates were doing—and the results were such as they had no reason to be ashamed of.

While I believe there is plenty of room for schools on the plan proposed, it does not follow that all cities need their school systems carried out in the same way. Certainly there should be schools with building aims as well as machinists, stone-cutting and carving, carpentry and joinery, bricklaying, plumbing, etc.; in fact, schools to prepare young men and women for all the activities of civilized life—one as well as another.

Some one has said that "mathematics is a tool to work with." What else is an education? and if a tool, why should not the tool be the best that can be devised for the workman to use in the trade he is to follow? Is it not time for the practical mechanic, the engineer, the architect to suggest, as Mr. Higgins has done in the arraignment, what sort of an education is best for the mechanic, the engineer, and the architect, rather than for the educator to dictate what it shall be? If our engineering students got a good deal more of an architectural and the architects a

good deal more of an engineering training, they would both be better off.

That every man, woman, and child would be better off with a liberal education is true, but, whether true or not, they cannot all have it, and what they do get should be, as Mr. Higgins indicates, such as will do them the most good up to the point where they have to stop. I am not prepared to admit that Mr. Higgins's scheme is the best that can be devised, though it may be the best or better than can be carried out. The very fact that he has shown that after a number of years a manufacturing school can be made more than self-supporting will no doubt appeal to the majority of our people more strongly than any other thing about it, but I am not one who believes in the notion that money-getting ought to be the great aim of mankind.

I would insist first upon doing things right, as that generally pays, and study economy and the paying part at the same time. If we can get trade-schools no other way than to make them self-supporting, then that is better than no way; and while I am not willing to go quite so far as indicated in the commercial directions, I would go further in the number of hours given to the handicraft and practical part, making it eight hours instead of half a day, believing two hours with the evenings for study will give all of that kind of work that students can remember; and, besides, I would make the work itself contribute to the instruction. The students should learn to use the English language by using it; they should learn to be gentlemen by being induced to act gentlemanly in all their intercourse; they should be trained to create their own rules and formulæ, and not learn them out of books: the work of the shop should be the quarry out of which the problems should be mined.

While writing this an article appears in *Machinery* from Prof. G. E. Gebhardt, of the Armour Institute of Technology, wherein he shows by actual experience that where the instructor has been through a mixture of study and practice, the results are decidedly the best.

Call it a shop with a school attachment, or whatever one likes, I believe the shop and the school should be one and the same, and under the direction of the man who is most likely to know what is best for the workmen, because, as is shown conclusively by the paper—in fact, known by every one—there are and must be from ten to a hundred workmen to every engineer; and, too—

what you all know—that every engineer ought to be a workman; and so why not make the workmen first, and then the foreman, the superintendent, the manufacturer, and the engineer out of those who are fitted for these positions?

I would not put all of the students through the same mill. If one had the ability and opportunity for a broad education I would guide him along through all the avenues of mechanical industries and business. If another seemed less capable or was restricted in time or resources, simply confine his time to that which he best liked or was best fitted for. If for a machinist, let the most of his time be spent in a machine shop, with enough drawing to read drawings, enough pattern work to only get an insight, and so much foundry work as to give him what a good many machinists never learn—a respect for the foundryman. A draughtsman, to be good for much in an engine or machine-tool shop, should be a pattern-maker, a foundryman, and a machinist, and he should practise his drawing while he is learning these trades, that he may learn what is of the most value—not only the relation the drawing bears to the thing, but also from the drawing how the finished work will look. A foundryman, to be a good one, in all its branches, has enough on his hands if he knows enough about drawings to read them.

This all aims to making specialists of even those who learn the trades; and this all the professors and teachers are going to object to, repeating "the oft-told tale" that what in our republican form of government and modern civilization we must do is to educate our people—not make specialists—but give them broad and liberal educations, forgetting that the professors and teachers are themselves specialists, and that it is not the men with trades that fill our poorhouses and prisons and pollute our political body, but the ignorant, the indolent, and the idle-educated. One who receives an education at the expense of the State, unless he does something to change useless material into useful, something for others or the State gratuitously, ought he not to be looked upon as a disgrace, rather than an ornament to society?

Mr. S. W. Baldwin.—It is all important, in discussing this paper, to note that Mr. Higgins's proposition is not a general system of boy education, but that he confines himself to a small percentage of the school boys, and these to be carefully selected. These boys will leave the Half-time School at the same age they would otherwise have left the high school, and the question

under discussion is: Will the selected boys when leaving the Half-time School be better fitted to begin the battle of life, will they make better and more useful citizens, than the same boys would if they had taken the high-school course?

It has occurred to me that there is a striking parallel between guns and education. The old-fashioned gun was big, made ornamental, badly proportioned, used a large ball of soft material, made a lot of smoke and noise, was aimed at the clouds with the hope that the ball would somehow strike somewhere and do some execution. The old-style and much of the new education is very much like this. The modern gun is devoid of all ornamentation, well proportioned, good material, small bore, steel shot, makes but little noise, no smoke, is aimed at the mark, pretty sure to hit and do execution. In other words, the modern gun is made for a definite service, and is a success. So, too, the boy should be educated for a definite service, and from an early age the education should be aimed at the mark, and not as now pointed, in a general direction, in the hope it will somehow hit something somewhere.

As compared with what is now being done in trade schools, perhaps the most distinctive character of Mr. Higgins's proposition is its commercial feature. Whether or no this can be made workable is its most important question. Had the proposition come from one less informed I should have serious doubts as to workability. Admitting that the results would be equal, Mr. Higgins estimates these are so far-reaching in effect it is safe to assume that if the problem was undertaken by earnest, able men a satisfactory solution could be found.

I very much fear the proposed union with the public schools would result in difficulties and compromises that would militate against decided success. Were I responsible for the solution of the problem, I am inclined to think that I would promote it exclusively as a commercial undertaking. I would try to demonstrate to those who would be asked to furnish the money that we offer them a safe—say 8 per cent.—investment, thus confining the element of benefaction to the willingness of the proposed investors to take the risk of the investment and spending the time necessary to see that the management was the best possible. I think that this risk would be less if the management was free from any interference of the public-school authorities.

The question would then resolve itself into this: Can a manu-

facturing corporation employing, say, twenty-five selected skilled workmen at, say, wages of $3 per day, and fifty boys at no wages, be made to earn dividends of 6 to 8 per cent. on the money invested? In lieu of wages of fifty boys, one hundred boys are to receive school and shop instructions of a high order especially adapted to the end intended, viz., fitting each boy to earn an honest living at the end of his four years' course.

The income would be divided from the sale of the output of seventy-five workmen at an average wage of $1.12 per day. The outgo would be the cost of maintaining the school in addition to the usual cost of maintaining the shops. If under these conditions a small profit could not be made, then ask of the public-school authorities to pay to the corporation a sum of money annually equal to the cost of the same number of school hours in the established high schools, as is furnished by the incorporation in the Half-time Schools. If additional public aid was needed, ask the State legislature to remit all taxes upon the real estate and personal property belonging to the corporations. In return, give the public authorities full opportunity to inform themselves of the results, that they could satisfy themselves the expenditure of public money in the Half-time School produced results equal to, or greater than, the expenditure of the same amount of money in the high school. Assuming that this arrangement had been made with the public authorities, and that the profits of the corporation should be greater than the agreed dividends, the surplus is to be placed in a sinking fund. When this sinking fund was sufficiently large, it should be used to establish another Half-time School in another city in the State, or to enlarge the existing school to other industries. I believe the manufacturing interest of the State would look with favor upon the Half-time School, and lend it countenance and aid in many ways.

As to what should be manufactured in a Half-time School, I should try and avoid open market competition. The articles made should be of a character to afford variety, representing the different classes of work best suited for instruction. Both these objects could be attained by contracting with established manufacturers to furnish them with special parts of the machines they make. The management would be on the lookout for new industries about starting, and make propositions to furnish certain parts of the new machine they were about putting on the

market, thus avoiding the necessity of the new concern fitting up to make the particular parts in question. In this way the Half-time School would keep in touch with the manufacturing interests of the State; would be regarded by it as a helping friend and not as a rival, and so secure its aid and coöperation.

What Mr. Higgins says as to his knowledge derived from actual experience, of the receptive faculty and earning capacity of the selected boys at the age of fourteen to twenty, has a very important bearing on the probable commercial success of the undertaking.

The fact that during the whole of the boy's four-year course he is living in a commercial atmosphere, and is associated with men who appreciate and know the actual money value of an hour's time, will have an effect upon the boy's future hard to estimate. The value of this to the boy is second only to the value of the school and shop training. The effect of this combination has never, as far as I know, been secured to the class of boys in question by an existing system of education in this or any other country. If this movement results in the establishment of Half-time Schools throughout the country, even to a limited extent, too much credit and honor cannot be accorded to Mr. Higgins.

Reference is made in the paper to the effect of a more thorough education of the rank and file of our journeymen, foremen, and superintendents on the export business of our country. To the extent we have and are succeeding in selling our high-grade machinery in the open market of the world, I think is largely due the fact that those who actually do the work are, as a class, better educated, more self-respecting, self-reliant, independent thinking and acting men than are the corresponding class in any other country. To maintain and better the position we now hold no movement can be more effective than to make adequate provision for the better education and training of the boys who are to become the men who actually do the work, and those who are directly associated with them in directing how this work should be done.

So long as we keep ahead of our competitors in these respects so long will we be leaders rather than followers in supplying high-grade machinery and manufactured articles to the open markets of the world.

It is safe to say that no body of men realize as emphatically as do the men composing our membership the fact that in these

latter days it is *intelligent* labor rather than *hard* labor that counts. What more potent action can we take to maintain and make better our position than to take the necessary steps to increase the average intelligence of the labor that actually produces what we have to sell?

Mr. Robert W. Hunt.—I wish to add my tribute to Professor Higgins for his paper. I regard it as one of the most important papers ever presented to our Society. I think there is not an employer of skilled labor within the sound of my voice to-night who does not recognize that to-day the American manufacturer is over a volcano that may burst at any moment and overthrow and submerge this great prosperity that now makes us so happy. Why? The threatened domination of the trade union. I happen to know the manufacturers are endeavoring to fortify themselves against it, but the better way to meet the difficulty comes from the foundation of the paper which you are discussing to-night. As I understand it Professor Higgins is not discussing the making of mechanical engineers as they come from our greater engineering schools. He only proposes developing them upon the foundation of a mechanical education. Now it is in the education of the boy who is coming up to make him a better boy, and to make him a sound and intelligent mechanic, to go into your shops. If he can go further and become a foreman, or still further and become a mechanical engineer, so much the better, but it is the first step as a solid foundation which constitutes the professor's scheme. I think, in the discussion which has taken place, that fundamental fact has been lost sight of. It is not that this school is to supplant our greater schools—not at all! But if it is the duty of the State to educate the boy to read and write, it is a higher duty to make him a good citizen after he learns to read and write. (Applause.)

You put a boy into a shop equipped with the education which he would receive from contact with intelligent instructors and skilled mechanics, and the walking delegate, who can, as a rule, neither read nor write a single sentence in the English language correctly, will have no power over him. (Applause.) And beyond that, he will act as a leaven upon the whole shop. American manufacturers are anxious in relation to the labor outlook, and realize the dangers threatening. How shall we meet them? We Americans pride ourselves that we are competing successfully in foreign markets. Why? Because here to-day it is not

one man to one machine, nor the extent of the production of man's or machine's day's work limited; but you know, many of you listening to me, that the movement to overthrow this is in many shops, and the longer our prosperity continues the sooner the revolution will come to us; it will be one man to one machine, and no "handy men" permitted. Now how are we to meet this? Meet it by making the young man who goes into your shop intelligent enough to know that his employer is his best friend, as he should be. To know that his labor, his skill in his labor, is his own capital, and as he can independently and intelligently exercise that capital, so it shall surely bring him good results. Therefore I say to you, gentlemen, in my best judgment, the scheme proposed by Mr. Higgins, modified somewhat as it, perhaps, will have to be—but as a basis it is among the best and the greatest contributions towards the success of our good and glorious country that has ever been presented, and I congratulate you, sir, and our Society that it should come through us. (Applause.)

May I detain you one minute longer, to interject a thought that I failed to express? It was the question of the competition of this proposed paying shop school of Professor Higgins. Now, they may not all pay; but don't you think that the manufacturer might take the risk of competition from them when they are taking that risk of competition from the unpaid labor of the penitentiaries? It seems to me that as long as we are allowing penitentiaries to send out manufactured products, we might let a few schools enter the competition. But I think we all have the idea of mechanics and of machinists and of manufacturing works too much in our minds, neglecting what a great blessing it would be if we could get more young men of the country to forget that there were such things, and so have as their ambition the cultivation of the broad acres of land yet waiting the tiller. If we could stop this congregation in cities and send emigration from foreign countries to till the fertile plains which are waiting for cultivation, and so let every man of brawn and brains acquire a home where he could raise his children and be happy right under his own vine and fig-tree, it would be the greatest blessing which could happen to our country. So while we are devising the mechanical schools, don't let us forget that an equally good movement, to my mind, would be a branch of school life which would tend to cultivate a desire in

the minds of the working classes of the cities to go away from them, and to keep many others from coming to them.

Mr. John Fritz.—I have not got up to make a speech; it is a good deal easier to be critical than it is to be correct. (Applause.) I have listened to these papers with a great deal of interest, and I am not going to find fault with any of them. But there is one thing which strikes me that we all have missed. I would like to know what is going to become of the children of the breadwinners: how are they going to get their education? That is the problem which has always been troubling me. In Pennsylvania we have a law requiring children to be sent to school until they are sixteen years of age. This law is necessarily disregarded. You take a family of five or six children, the parent only earning a dollar or a dollar and a quarter a day, how is he going to live and raise that family in such a way as to make good citizens out of them? These are problems which we have got to take hold of, and when we do so, and in the proper spirit, many of the troubles which now annoy both the employer and employee will, in a great measure, disappear. How is the boy going to get an education? I believe that the manufacturers themselves could do this, and were I in control of an iron and steel plant I would certainly make the experiment. I would establish the best schools and the best adapted buildings and the best teachers that money could hire, and the boys should come into the works whenever they are able to. As Professor Sweet truly said, it is not necessary to spend five or six hours a day to teach a boy. But establish a school with the best teachers you can get; not only a school, but give your boys a gymnasium, give them everything that you can to induce them to become interested in their work. Now, that is the way to make your foremen and the way to make your mechanics.

If you will watch the boys that go in to carry water and do little chores, you will soon find the proper place for them. You can't make a machinist of a man who has no taste for it. People say that engineers are born. Ability is born, but you make the engineer; and it is just so with the mechanic—you have got to make him. The best men I ever had came up in the works, and only wanted an education to make them still better. In adopting this course there will be fewer misfits and disappointments, and the brighter boys will be in the best possible condition to enter college, to make mechanical engineers, and highest grade of foremen.

Prof. Arthur L. Williston.—There is one point in Professor Higgins's paper which has not been brought out, yet I think it is of a good deal of importance. I refer to the necessity in a trade school of having some kind of educational training to cultivate the mind at the same time that the eye and the hand are being cultivated to the trade. You cannot make a machinist or any other mechanic by cultivating skill of eye and hand alone; you must train the mind at the same time; and I think this idea of a Half-time School, devoting half time to teaching the trade and half time to mental training, is a most excellent one. The trade school, as it originally sprang up in this country, embodied the idea of devoting the entire time to learning the trade; the boy was to spend his entire day working at his trade, with the idea that by concentrating the entire energ yon the acquiring of skill, the best results could be reached. The part that judgment and intelligent direction of effort played in the make-up of the good mechanic was forgotten, or else it was not realized that these valuable qualities could best be obtained through the growth of reasoning power founded on some knowledge of mathematics and science. The common-school system does the other thing. It goes on the assumption that the only way of getting intelligence into the brain is through the ears and through the eyes in reading books, forgetting that much can be learned by doing things. Now, it seems to me that the ideal way is the way which this paper suggests, of having both elements come into account, having the skill of the eye and the hand cultivated at the same time that the mind is trained.

Professor Higgins points out how some thirty-five years ago the problem of training scientific engineers confronted the country, and he shows how excellently the technical colleges of the country have met this problem. It seems to me that to-day the problem confronts us of training young men, not as engineers, but, as Professor Higgins says, as foremen or overseers, men who can plan and direct work, not only in machine shops, but in all our shops, factories, and in all our industries. It is a hundred times more important to-day that this problem should be met than it was thirty-five years ago that the problem of training engineers should be met as it was, because a hundred of the men that Professor Higgins describes are needed to-day to every one man of the other type. And toward the solution of this problem, I think the suggestion of devoting half the time

to training on one side in the shops and the other half the time to training on the other side in the school, is a most excellent and valuable one.

A number of objections have been raised that the plan is in some of its features impracticable; but those objections do not seem to me to affect very much the essential points in the paper. If there are difficulties of one kind or another in the way they can be overcome. It is not absolutely essential that the exact details should be carried out; but the fundamental principle of the paper, it seems to me, is very, very significant.

Mr. Horace See.—It has given me great pleasure to listen to the discussion here to-night, particularly as I called attention in 1888 to the subject of educating the rank and file, and as the hour is late, I refer the members to my address as retiring president in 1888.

The President.—Thank you, sir.

Prof. George I. Alden.—In order to represent, on a single page, a distribution of time which I think Professor Higgins contemplates between the shop and the school, I have prepared a possible hour-plan for such a school, with a few remarks regarding the methods of teaching which would be adopted, which at this late hour I will not read, but with your permission will hand to the secretary. It may be printed with the discussions if he thinks that best.

First Year.

A. M.

Monday.....	Algebra.	English.	Drawing.	Drawing.
Tuesday.....	Shop practice.			
Wednesday.....	Algebra.	Rhetoric.	French.	
Thursday.....	Shop practice.			
Friday.....	Algebra.	English.	French.	

P. M.

Monday.....	Shop practice.			
Tuesday.....	Algebra.	French.	English.	
Wednesday.....	Shop practice.			
Thursday.....	Drawing.	Drawing.	French.	English.
Friday.....	Shop practice.			

Second Year.

A. M.

Monday	Geometry.	English.	Drawing.	Drawing.
Tuesday	Shop practice.			
Wednesday	French.	History.*	English.	
Thursday	Shop practice.			
Friday	Geometry.	English.	French.	History.

P. M.

Monday	Shop practice.			
Tuesday	Geometry.	French.	History.	English.
Wednesday	Shop practice.			
Thursday	Drawing.	Drawing.	Geometry.	English.
Friday	Shop practice.			

Third Year.

A. M.

Monday	Physics.	English.	Drawing.	Drawing.
Tuesday	Shop practice.			
Wednesday	English.	Physics.	P. Lab.	P. Lab.
Thursday	Shop practice.			
Friday	English.	French.	Drawing.	Drawing.

P M.

Monday	Shop practice.			
Tuesday	Physics.	History.	English.	
Wednesday	Shop practice.			
Thursday	History.	French.	English.	
Friday	Shop practice.			

* Outlines of the world's history.

Fourth Year.

A. M.

Monday.....	Bookkeeping.	Bookkeeping.	English.	Chemistry.*
Tuesday.....	Shop practice.			
Wednesday.....	English.	Commercial Law.	Chemistry Lab.	Chemistry Lab.
Thursday.....	Shop practice.			
Friday.....	Bookkeeping.	Bookkeeping.	English.	Chemistry.

P. M.

Monday.....	Shop practice.			
Tuesday.....	Commercial Arithmetic.	Bookkeeping.	Bookkeeping.	English.
Wednesday.....	Shop practice.			
Thursday.....	Commercial Arithmetic.	Commercial Law.	English.	
Friday.....	Shop practice.			

(1)	(2)	(3)	(4)
Algebra, 4.	Geometry, 4.	Physics, 5.	Bookkeeping, 6.
French, 4.	Drawing, 4.	English, 5.	English, 5.
Drawing, 4.	English, 5.	Drawing, 4.	Commercial Arithmetic, 2.
English, 5.	French, 3.	French, 2.	Commercial Law, 2.
	History, 3.	History, 2.	Chemistry, 4 (half year).
			Political Economy, 4 (half year).

Most of the studies scheduled are those of an ordinary high school. To avoid making the home study too burdensome, the courses in rhetoric and English are planned to be carried on entirely in the class-room, a thing less possible in the case of mathematics, languages, or science. The rhetoric should consist of writing short themes in class, which would then be corrected by the teacher, and carefully criticised and discussed in class at the next appointment.

The work in English is designed to give the student an appreciation and enjoyment of good literature, and to make him familiar with the masterpieces of our own tongue. It would consist of reading in the class room the best poetry and prose, with carefully conducted class discussion, supplemented by the

*The second half of the fourth year chemistry would be replaced by political economy.

teacher with any necessary explanations, information as to the author, his literary position and achievements, etc. If any preparation could be required of the student, it should be in reading and becoming familiar with the piece studied, not in acquiring information which the teacher could supply. At the end of such a four years' course, if it were well planned and conducted, the pupil would not only have been given much enjoyment and been stimulated to private reading among the best books, but he would also have made the acquaintance of all the greatest authors and masterpieces of our literature, while he would have gained from them a degree of literary appreciation and of culture far surpassing that usually found in high school graduates.

The Half-time School should be carried on with two divisions. The above hour-plan gives the schedule of one division. The other division would have shop practice on the half-days that the first division recited, and vice versa, so that both the shop and the school-rooms would be in constant use.

Mr. F. A. Halsey.—There is scarcely a page of this paper which does not contain material for discussion. In the face of Mr. Higgins's experience, all opinions which express doubts of the practicability of commercially productive shops as departments of engineering schools fall to the ground. Mr. Higgins may fairly claim to close the discussion on that topic.

To me the most suggestive single sentence of the entire paper is the following: "There are marvellous possibilities of skill and invention among a class of boys who are never thought of as possible engineers, boys who sometimes make themselves leaders among the favored ones of the earth." No one can be acquainted with what has been accomplished by men who have thus come up from the ranks, or with the men who still fill the ranks, without agreeing with this statement. Our position in the international machinery market is due to our productive methods more than to anything else, and in so far as these methods differ from those used elsewhere, they are almost wholly due to men of this class. The academic engineer, if he devotes himself to production at all. is much more apt to take up the designing than the constructing end of it.

The importance to the country of the work of the shop man cannot be exaggerated, and I am fully persuaded that the engineering educational problem of the day and of the country

lies in the bringing of it within the reach of these men. There is to-day an absolute famine of leadership talent in the shops of this country, while latent talent sufficient for all needs abounds; the only thing lacking being the means of developing that talent. The difficulty in the way of such latent talent developing itself and forcing itself to the front increases every year. When our industries were in a more primitive condition the kind of knowledge which came through the ends of the fingers was of far greater importance than any that came by way of the head; but at present, while the importance of this finger knowledge has not diminished, the need of head knowledge has been added to it, and the problem of the day is the placing of the latter within the reach of those who already possess the former.

In spite of the success of our engineering schools, and of their graduates in commercial life, I insist that they are based upon a false foundation, that foundation being the high school, whereas it should be the machine shop. In the early days of American engineering education, a fair proportion of boys from the shops succeeded in scaling the fence which had been built to keep them out—the entrance examinations—because the fence was then of moderate height; and, it may be added, those boys were the "little leaven that leavened the whole lump." Year by year, however, the fence grows higher, and at present its height is such that unless a boy has spent all his school years in the school-room he cannot get over it. In other words, the engineering schools have deliberately shut out the shop boy and cast their lot with the high-school boy, and I suppose they have their reward—though I do not know what it can be.

For years it has been my hobby that boys who had already served an apprenticeship should be admitted to the existing engineering schools alongside the boys from the high schools—the shop work of the one being accepted as the equivalent of the school work of the other—and this idea has been presented to educators repeatedly. It has been met with objections, of course, chief of which is the confusion involved. This difficulty, of course, exists, and is serious, but in view of the end to be accomplished, it is not one which should rule. The school which, instead of studying the difficulties, will deliberately declare that this thing shall be done, will find the means of doing it. That there is anything impracticable about the giving of engi-

neering education of the soundest and most thorough character to these shop boys is absurd.

A second objection is that the plan involves the teaching of primary studies. "This school is of university grade, you know. We cannot be expected to teach common arithmetic, algebra, and such subjects. The public schools are intended for that." With this idea I have no sympathy whatever, and to it my regular reply has been that it is no more beneath the college of engineering to conduct a primary school than it is to conduct a primary shop. Look at the early exercise work of the regular instruction shop—at the spools, paper-weights, and things which are made as exercises, and then tell me by what process of reasoning this sort of thing has been dignified into a fit subject for university teaching. Not a shadow of reflection upon the teachers who are doing this is intended—they are doing the best they can, and the only thing they can with the student material they have—but what shall be said of the point of view which includes the teaching of the most simple operations of the shop as a branch of the university curriculum, but excludes arithmetic and algebra, for example, as unworthy? What shall be said also of the policy which deliberately selects, as the best timber whereof to make the future engineer, the high-school boy, through an examination test which has no relation to his mechanical ability or taste, and as deliberately discards the shop boy who is one bundle of springs and wheels? By what right is the high-school boy given elementary instruction to meet his deficiencies, while the shop boy is denied the elementary instruction to meet his? The fact is, the boy who has served an apprenticeship is just at the point where he is ready to begin to acquire some of the shop knowledge which an engineer needs to have.

The engineering schools of the country have simply been patterned after one another with scarcely an original idea in one of them since the first, and they are to-day one grand illustration of the truth of that saying of old: "To him that hath shall be given, and from him that hath not shall be taken even that which he hath."

However, it is clear that existing schools will make no change. The idea is too far removed from the academic atmosphere which surrounds them. It clashes too much with the fundamental idea that their proper foundation is the high school.

Under these circumstances it only remains to hope and to wait for the organization of a new school which shall take boys from the shop and from nowhere else—which shall make it a fundamental requirement for admission that the applicant shall have served an apprenticeship or its equivalent. It needs no gift of prophecy to foresee that the graduates of such a school would be men whose interest in life would centre in the design and construction of machinery, and not in this everlasting programme of weighing and measuring, testing and the figuring of efficiencies, etc.

There is another aspect to this whole matter which relates to the subject of self-support, or partial self-support, by students. Pretentious experiments have been made in this direction which have failed, and from the failures the impression has gone abroad that the idea of systematically offering means for self-support is impracticable. Those who know most about these experiments set the least value upon them; but, regardless of such considerations, it should be remembered that all the efforts which have been made in this connection have aimed to supply an opening for unskilled labor only—a fact which alone added enormously to the difficulties of the experiment. The plan here outlined contemplates the assemblage in considerable numbers of students who are already skilled workmen. In view of Mr. Higgins's demonstration—for it is nothing less—of the practicability of the college shop being a real productive shop, is there any serious difficulty in the way of paying such students for the work done? I am unable to see it. On the contrary, I believe that the plan here outlined offers a field for a most fruitful experiment, and a result of which competent educators have long dreamed.

Such a school, it is needless to say, would in the highest possible degree represent true Americanism and the best American tradition—the tradition that here every man shall have a chance. Endow it with sufficient funds to enable it to pay salaries which will attract men as teachers who in commercial life have acquired experience as designers, constructors, and administrators, and engineering education will enter upon a new phase. The art of conducting a machine shop becomes every day more and more complex. There is a large and unoccupied educational field for this class of work, which is just as appropriate to systematic teaching as any that exists, and for which men to-day can fit them-

selves only by the old process of "picking up" information in scraps. Men who can do such are in great demand, and it is time something was done to fill a proven want. Can anyone doubt the quickening effect through all the machine shops of the land of such a goal for ambitious boys? It makes one's blood tingle to contemplate what such a school could do both for humanity and for the country. Build it as large as you may, it cannot be made large enough to hold the students that would flock to its doors.

Mr. W. S. Rogers.—This is indeed one of the most interesting papers presented to our Society in a long time. Early in life I was well instructed by excellent teachers concerning the all-important principle underlying successful shop and factory management, but I wandered away from my early teachings, and became a sort of fanatic on "cost-keeping"; and I wish to apologize to my friends for all my sins in that direction, as I now let costs keep themselves automatically, and I believe that the man who has such a fad as his prime motive never earned a dollar in his life.

This paper touches upon a problem every manufacturer has to solve over and over again, and not a critic or doctor in the discussion to-night has mentioned it or suggested a remedy.

The entire meat of this paper is found in the second paragraph on the second page, and the author has emphasized it that he who runs may read. He says, "If the position of machinist is hard to fill, what is to be said of that of foreman?" There is all the meat of the nut. We are teaching all kinds of ethics but those of discipline and organization; making all kinds of "designers," but not a single, real, live article in the way of an organizer and disciplinarian. It is no wonder if we find the majority of the technical instructors arrayed against this paper. How can any man teach a science about which he knows but little? Our manufacturers are to blame for abandoning the old-fashioned apprenticeship system, and not keeping in close touch and contact with their men. The author goes on to say that the positions of president, treasurer, mechanical engineer, and salesman "need not wait a day for applicants." Too true, and these appointments are not always according to the eternal fitness of the case either, but through politic motives. You may choose the brightest genius that ever came from Yale or any other university, and call him president or what you will

of a corporation, and unless he knows the sublime importance of discipline and organization, and chooses his subordinates according to their ability in this direction, meddles not with their methods, but demands only results, he will have the same troubles that began after the world's creation, and the only salvation to prevent the concern going "broke" is to form a trust and get in it quick. (Laughter and applause.)

The Tower of Babel was started to heaven and suddenly stopped. Why? Because there was no discipline or organized method, and every fellow tried to run the business to suit himself. Lack of organization caused all the trouble we have had since the battle of Santiago as to "who did it." We can easily read it in the lines, as well as between the lines. Not sailorship, statesmanship, or technical knowledge of bending stresses, but a grand organization and perfect discipline of the human forces under him, gave Dewey that famous victory in Manila Bay, and every man who rode from Washington to New York with that carload of sailors who returned with the "Raleigh," and heard them tell us over and over again the story of the fight, with "breakfast for intermission," and how "the old man" Dewey did it, will say it was not because he knew how to set a sail or steer a ship, but because he had organized a trained human force that was irresistible, and they had absolute faith in him. He knew where to draw the line between comradeship with his men and respect for superiors, and he kept the line taut. (Applause.)

The greatest battle ever won in Israel's history was gained how? By organization; for history tells us that "every man stood in his place that day." Go into our shops when the starting bell rings, or the whistle blows, and see how few of the men are in their places, and also how few of the foremen are in their places. No organized method, and dollars lost. Who is to blame? Surely not the technical schools, for this is something beyond their ken. Nobody to blame? Let's see. We note in the *American Machinist* want columns every week such advertisements as this: "Wanted—A foreman that is a hustler. State lowest salary you will work for." (Laughter.) Simply endeavoring to get something for nothing. We want brains, but don't want to pay for them.

Old King Solomon built a temple, and history informs us that it was done so expeditiously that no rain fell on it. Per-

selves only by the old process of "picking up" information in scraps. Men who can do such are in great demand, and it is time something was done to fill a proven want. Can anyone doubt the quickening effect through all the machine shops of the land of such a goal for ambitious boys? It makes one's blood tingle to contemplate what such a school could do both for humanity and for the country. Build it as large as you may, it cannot be made large enough to hold the students that would flock to its doors.

Mr. W. S. Rogers.—This is indeed one of the most interesting papers presented to our Society in a long time. Early in life I was well instructed by excellent teachers concerning the all-important principle underlying successful shop and factory management, but I wandered away from my early teachings, and became a sort of fanatic on "cost-keeping"; and I wish to apologize to my friends for all my sins in that direction, as I now let costs keep themselves automatically, and I believe that the man who has such a fad as his prime motive never earned a dollar in his life.

This paper touches upon a problem every manufacturer has to solve over and over again, and not a critic or doctor in the discussion to-night has mentioned it or suggested a remedy.

The entire meat of this paper is found in the second paragraph on the second page, and the author has emphasized it that he who runs may read. He says, "If the position of machinist is hard to fill, what is to be said of that of foreman?" There is all the meat of the nut. We are teaching all kinds of ethics but those of discipline and organization; making all kinds of "designers," but not a single, real, live article in the way of an organizer and disciplinarian. It is no wonder if we find the majority of the technical instructors arrayed against this paper. How can any man teach a science about which he knows but little? Our manufacturers are to blame for abandoning the old-fashioned apprenticeship system, and not keeping in close touch and contact with their men. The author goes on to say that the positions of president, treasurer, mechanical engineer, and salesman "need not wait a day for applicants." Too true, and these appointments are not always according to the eternal fitness of the case either, but through politic motives. You may choose the brightest genius that ever came from Yale or any other university, and call him president or what you will

of a corporation, and unless he knows the sublime importance of discipline and organization, and chooses his subordinates according to their ability in this direction, meddles not with their methods, but demands only results, he will have the same troubles that began after the world's creation, and the only salvation to prevent the concern going "broke" is to form a trust and get in it quick. (Laughter and applause.)

The Tower of Babel was started to heaven and suddenly stopped. Why? Because there was no discipline or organized method, and every fellow tried to run the business to suit himself. Lack of organization caused all the trouble we have had since the battle of Santiago as to "who did it." We can easily read it in the lines, as well as between the lines. Not sailorship, statesmanship, or technical knowledge of bending stresses, but a grand organization and perfect discipline of the human forces under him, gave Dewey that famous victory in Manila Bay, and every man who rode from Washington to New York with that carload of sailors who returned with the "Raleigh," and heard them tell us over and over again the story of the fight, with "breakfast for intermission," and how "the old man" Dewey did it, will say it was not because he knew how to set a sail or steer a ship, but because he had organized a trained human force that was irresistible, and they had absolute faith in him. He knew where to draw the line between comradeship with his men and respect for superiors, and he kept the line taut. (Applause.)

The greatest battle ever won in Israel's history was gained how? By organization; for history tells us that "every man stood in his place that day." Go into our shops when the starting bell rings, or the whistle blows, and see how few of the men are in their places, and also how few of the foremen are in their places. No organized method, and dollars lost. Who is to blame? Surely not the technical schools, for this is something beyond their ken. Nobody to blame? Let's see. We note in the *American Machinist* want columns every week such advertisements as this: "Wanted—A foreman that is a hustler. State lowest salary you will work for." (Laughter.) Simply endeavoring to get something for nothing. We want brains, but don't want to pay for them.

Old King Solomon built a temple, and history informs us that it was done so expeditiously that no rain fell on it. Per-

haps that was a slang way they had in those days of giving expression to their ideas of rapid work. To-day we would say there were "no flies on the job." (Laughter.) But how was it done? He simply sent over to another country and engaged a fellow who had a reputation for being a good organizer as well as being a good mechanic, and history tells us how well he organized the various gangs and produced results. The great trouble with us to-day is that we are too prone to go in the market places and discuss our ailments instead of reading up on history. (Applause.)

To-day I was with a large manufacturer who is starting a new business. Going through one department we found one man doing some unnecessary work, and the owner stopped him and asked, "Why are you doing this?" The man replied, "The boss is not around, and I am out of work and want to keep busy." The owner promptly ordered the man to "sit down on that pile of lumber and wait until your foreman comes round, and then tell him I ordered you to sit there; even if it should be for two hours, you stay there." After we were beyond hearing of the man, my friend said, "I want a foreman in another part of this plant in a few months, and am testing different men to discover their ability for handling men, distributing work, and getting results." He was not trying to get someone "cheap," but was solving the problem in a correct way. Afterwards he asked me "why our colleges, training schools, and educational institutions don't teach organization and discipline, the principal item in life that earns money for everybody," and I asked, "How can they?" The man must be born with inherent organizing influences within him. We can put young men through any school as we please, but if they have not ability or taste for the work, as Professor Higgins well says, we cannot make anything out of them. The phrenologist's advice is needed here.

Friend Hunt need have no fear of trades unions so long as we educate our workmen and let them see that merit wins. It is not for our Society to bother with this question, but we may well look at their methods of organization and discipline and learn lessons. Another study worth investigating when wanting more dividends is the Tammany organization—the very brightest example of discipline and subordinates chosen for their fitness in the world. If my friend Croker ever needs work

(and I hope he won't), and I am running some old foundry, he shall have a position as foreman, and no questions asked. (Laughter and applause.)

One remark more and I will stop. If the manufacturers of our country do not want to pay for the brains required of foremen to organize the different departments and gangs of physical labor, will not choose out such men and educate them by a system of merit, discipline, and tact without being brutal in the effort, then let them abolish the term of "foreman," because it is becoming meaningless, and substitute a man whom we will call "distributer of work," another man whom we will call an "inspector"; then hire a lot of policemen. (Applause.)

Prof. D. S. Jacobus.—I wish to express my hearty appreciation of the merits of this paper by endorsing all that has been said in its favor. That there is a demand for a system of education which will train boys to fill successive grades from machinists to engineers, and which shall be adapted to train each boy for each successive grade until his particular grade is determined by natural selection, there can be no doubt. In this way we would do much for a class of deserving young men, many of whom, by the present system, are held back through circumstances over which they have no control. The young men after passing from the school recommended by Mr. Higgins would have the foundation for an engineering education to be pursued later, and in this way any youth trained under the system might finally enter a field suited to his capabilities.

It has been pointed out in the discussion that the paper does not deal strictly with the education of the mechanical engineer, but with a general education which would form the basis of a mechanical engineering education; yet there are some allusions made by Mr. Higgins in regard to mechanical engineering schools which appear as adverse criticisms, and on which I wish to make a few remarks.

Some of these allusions may arise through looking at certain features from different points of view. For example, in the paper under the heading, "Another Unfortunate Result of Technical Schools," the statement is made that "the young man who enters an engineering school is allowed to get a false idea regarding his future, and that when after graduation he finds that he cannot do engineering work at all, or that there

are ten engineers to one position of that particular kind, and that every year the demand for professional engineers grows less and the graduates more numerous, he turns his attention reluctantly to a lower grade of work and is never quite satisfied or happy in it." Taken in the sense that the student may seldom rise to a position corresponding to the highest ideals and ambitions which come to him during his college life the statement is perhaps true, but when viewed in what is likely to be the popular understanding of ten engineering graduates to one position it is certainly incorrect. It is probable that Mr. Higgins had the first meaning in mind, and that the wording of his paper is unfortunate at this point. I cannot speak for all the engineering colleges, but can make the assertion from positive knowledge in regard to the Stevens Institute of Technology, where I serve as an instructor, that the demand for the graduates is increasing instead of decreasing. At our last commencement day nearly every member of the Senior Class had already secured a position, and out of our total number of graduates there are often times when there is not a single one unemployed that we know of to recommend for a position. We also keep a list of all our graduates who inform us that they are dissatisfied in the positions they occupy and who wish an opportunity to change, and many times we have no names on this list to chose from in answering applications for men.

Professor Sweet remarked in his discussion that the "Worcester School did that which no other school did, so far as he knew—published results, not how many graduates they had turned out, but what the graduates were doing." It might be well to state here that a list of all of the graduates of the Stevens Institute, giving the positions which they occupy, has been printed in each of the catalogues issued from year to year, and that an examination of this list will show that practically all the number are working in the engineering field.

There seems to be a tendency in Mr. Higgins's paper to class the mechanical engineer as one who has attained a high standard in the profession, and to criticise the mechanical engineering schools as not producing the mechanical engineer. In this Mr. Higgins looks at the matter from a wrong point of view. As an engineering school we do not graduate mechanical engineers as classed by Mr. Higgins, but confer a degree which testifies that we have prepared our graduates for making mechanical engineer-

ing their future career. The only way in which to determine whether an engineering education has been of the proper character is to note how the graduates have succeeded after they left their Alma Mater, and I feel that an examination of the list of the Stevens Institute graduates, which has already been referred to, showing what each one is doing, is the very best evidence that at least one of the mechanical engineering schools has been working in the right direction.

By Mr. Higgins's plan a young man would first have to become an efficient machinist, and after this a mechanical engineer. It appears to me unwise to adopt this policy. In the first place the students would be considerably older on entering the mechanical engineering school than they are under the present system, where no previous shop experience is required; and as the most receptive period, as Mr. Higgins has stated, is under twenty years of age, the students would be put to a disadvantage should they be given a long preliminary training in shop work, in having to pursue their studies which bear directly on mechanical engineering at a more advanced period of life than by the present system. President Morton, in a recent article, said that one of the secrets of the success of American manufacturing enterprise is due to the fact that younger men have been intrusted with the management of our affairs than is the case with our foreign competitors. These young men are more flexible in mind than those of more mature years, and are more willing to accept and try new ideas, and so have attained greater success in developing new methods and in achieving progress. The truth of this view of the matter is verified by so great a captain of American industry as Mr. Andrew Carnegie, who has said that the young men in his employ have made better progress than the older on account of not resisting new ideas.

In the second place there are many positions in the engineering field which do not require more than a general knowledge of shop practice, and this is exemplified by the fact that some of our graduates who have been poor in the shops have made striking successes in their chosen fields of work. A study of the work done by the various graduates also shows that many do not enter shops or fill positions in which they have a direct use for what is taught them in the shops.

It appears to me that the best plan is to give the students a

general understanding of shop processes during their college career by making them spend a limited number of hours in the shop, and after this to let those who wish to apply themselves to some manufacturing industry enter shops connected with the same. By this plan the students are made familiar with the underlying principles in engineering during the most receptive period of their life and graduate comparatively young, and with dispositions still flexible and capable of absorbing, carrying out, and developing the ideas of their employers.

It must not be inferred that I do not appreciate the benefits of a shop-work course. Far from this. Some of our best graduates are those who have served their time as apprentices, and have come to us at a comparatively late period in life, many of them using their own savings to pay their tuition fees; but it is harder for a man of this class to grasp the theoretical principles than a younger man, and frequently, unless such a student is given every encouragement during the first part of the course, he becomes thoroughly disheartened in his endeavors.

The question arises as to how much shop work should be given in an engineering school. Mr. Higgins appears to divide an engineering course into two parts: the theoretical part and the shop-work part. There is no education as efficient as where the students are made to work with their hands *in connection with* their heads. This I appreciate so well in my work as an instructor, that for every principle set forth in the class-room the students are required to make an experiment to verify or illustrate the same. A student will carry little with him after graduation, except what may be called the fundamental principles, and the power, necessarily obtained through a thorough drilling and work on his part, of correctly applying them. All formulæ and special rules will be forgotten, where principles once thoroughly mastered will not, and for this reason we strive to make the students thoroughly familiar with the principles before drilling them in the derivation and application of standard formulæ. This is done by making them work with their hands at the same time that they work with their heads in mastering the principles, after which they are made to apply the principles in solving a number of problems, all of which are based on data drawn from the practical field. In solving these problems, the students are not allowed to make use of any special formulæ given in text-books for the particular case, but

must base their work on the fundamental principles which have been given. What students do with their hands they remember so much better than the instruction they receive from lectures or books that I have noticed instances where, when puzzled in regard to the proper application of a principle, they would make a sketch of the apparatus with which they had experimented to illustrate the principle, in order to determine how to apply it.

Instead of tending to increase the amount of theoretical work required, as Mr. Higgins states is the tendency in some engineering schools, the tendency in most schools has been to introduce a greater amount of hand work from year to year. The shop work done by the students is only a part of the work which they do with their hands. As an instance, let us see what hand work is done, other than shop work, in the college with which I am connected. There is work of the character of setting of the valves of steam engines; taking indicator cards for various settings of the eccentric and valves; calibrating indicators, etc.; adjustment of counter-weight so as to produce the minimum amount of shake in an engine; variation of the amount of compression or cushion of steam at the end of the stroke so as to produce smoothness in running; and a number of similar exercises, in all of which the students work with their hands. In addition to this there is a large amount of experimental work, in some of which the students are required to work for eight hours, or over, per day; such as, tests of the properties of materials of construction, tests of steam boilers, steam engines, pumps, and numerous other devices. Supplementary to this there are the courses in the electrical and physical laboratories in which each student has to perform delicate operations, and in which the precision of his work is an important feature. This is especially so in the physical laboratory, where the students are given a course (which is classed as engineering physics) in which the exercises bear directly on engineering work, and include such exercises as those involving precise measurements of length; the measurement of temperatures by means of mercury and air thermometers, and all standard pyrometers; measurements of quantities of heat, such as the heat of combustion of gas by the Junker calorimeter and of coal by the Mahler calorimeter; together with many other exercises of the same class. In addition to all this the students work with their hands in the draughting-room and in the chemi-

cal laboratories, so that out of all the time spent at the institute the students devote less than one-third to class-room work. That with this amount of training the students become expert in work requiring careful manipulation is made manifest in a most satisfactory way toward the latter part of the course by the accuracy of the results obtained in their experiments and the ease with which they handle apparatus of a most delicate character.

Mr. Higgins states that the establishment of machine shops as a department in technical schools resulted in what is known as *instruction shops*, as distinguished from *construction shops*, and goes on to say that in either case the sole object was instruction, and this was accomplished in the former plan by exercises which produce something neither intrinsically good nor useful. He then goes on to class the exercise system as "play at hospital practice," and remarks: "What would the heads of our most progressive professions think if it should be urged that it would be just as well for young surgeons to play at hospital practice instead of performing real surgical operations, getting over real difficulties, and saving the lives of patients?" He further states that "If a young man is not practically trained in the anatomy of the machine shop, and cannot note the weaknesses and meet the emergencies of it . . . the enterprise . . . may die like the patient who lacks the competent care and skill of the doctor." It appears to me that there would be more sacrificing than saving of the lives of patients should the young surgeons be made to study anatomy by performing real surgical operations. Anatomy, in surgery, is taught in the dissecting-room, and the dissecting-room stands in the same relation in a course of surgery that the exercise system in shop work does in a course of mechanical engineering.

The advantages of the exercise system are that the exercises may be designed so that the students may be made familiar with a number of different classes of work in a short time, and the students who are apt to make mistakes may be given the same course of training as those who are better workmen. In commercial work there are parts of some machines the construction of which cannot be intrusted to the students who are the poorer workmen, and these poorer workmen do not receive as much advantage from the course as those who are given the higher class of work. This infers, of course, that the shop-

work course is of a limited duration, so that there is not enough time in which to make all the students efficient workmen.

If we are to train men for positions as machinists, then there is probably no better way to give instruction in the shop than that recommended by Mr. Higgins. If, on the other hand, we are to give the students a limited amount of shop work in order that they may have a general understanding of the use of tools, the exercise system is preferable, as it allows the majority of the students to be placed on more advanced work than could be assigned to them in a commercial shop, and also allows the exercises to be so arranged that the students are made familiar, in a comparatively small space of time, with all the standard tools and processes.

Another feature in commercial work which may detract from the value of the instruction, is that the efficiency of the instruction may be sacrificed in order to run the shop on a paying basis. The best results, as far as economy is concerned, are obtained by keeping each of the students on the same class of work, whereas, when instruction alone is considered, the best results are obtained by making the work of each student as varied as possible.

Prof. Wm. T. Magruder.—The Society is to be congratulated for obtaining from Professor Higgins such a complete statement of the educational "faith that is in him" and of his twenty-six years of experience, both as an instructor of young men in the mechanic arts and as a machinery manufacturer using a large amount of students' labor. When a man of his wide, practical experience is so kind as to record for others the results of that experience, it may seem almost presumptuous for those who have had only half the number of years of experience in the same line to discuss the problem so presented; but, as it is one of vital importance to teaching engineers and of general interest to all, it is to be hoped that the discussion will bring out the opinions both of those engineers with experience in the "education of machinists, foremen, and mechanical engineers," and also of those who are now using their services.

While it cannot be denied that there is a great and increasing demand for the technical education which is required by the artisan, as was shown in the paper on "Correspondence Schools," by Professor Marburg, at the last meeting of the Society for the Promotion of Engineering Education, yet it is

not just to our engineering schools that they should be charged with the failure to reach this class (page 4). With a few exceptions, they have never offered a curriculum suited solely for artisans, and have from the beginning stated as distinctly as possible that their business was to educate engineers, and not men who were only surveyors, analysts, miners, draughtsmen, or mechanics. Every teaching engineer has been aware of this need from the number of requests which he has had to decline of young men who desired to take special courses in shop work, drawing, etc. But the catalogues do state that if the applicant is of proper age and can "furnish credit for elementary or 'grade' work, and for such other subjects as may be necessary to qualify him for the class that he may wish to enter, he will be admitted to any class." Many young men have availed themselves of this general practice of our engineering colleges, and have, with only a grammar-school education, entered and done the work of certain of the regular classes in English, mathematics, physics, drawing, and shop work, and have left after a year so spent, the better prepared for their life's work. In connection with many of our engineering schools will also be found so-called short courses in mechanic or industrial arts, in mining, and in clay-working. To quote from the catalogue of the College of Engineering of the Ohio State University, "These courses are provided to meet the needs of a large class of young men who for any reason will not or cannot obtain the benefits of the thorough and longer courses. The university recognizes that there are many valid reasons which may stand in the way of young men whose ability to receive and use the highest forms of education is without question, and it is thought that in extending opportunities for such training as will be available for such young men, the university is filling a long-felt want in the scheme of engineering education, and is certain to grow into closer contact with the industrial life of the State." At this institution it would seem that young men who can afford to go away from home and pay even the $150 to $225 which are necessary for board, lodging, books, and clothing during the nine months spent at the university, do not desire a course in mechanic arts, but ask for something higher. If they have money to spend on so-called full-time technical education, they much prefer to spend it in the work of the first and second years of the College of Engineering, with the hope that at some future

time fortune may smile on them to such an extent as will enable them to return, finish their course, and take the coveted degree. And even if they never return, they make the better men and citizens for having had a year's work in science, English, drawing, and shop work, and for having associated with college men.

The engineering colleges, with possibly a few exceptions, have never claimed to turn out all-around mechanics, but rather to give instruction in just those principles and shop processes which will enable a young man to talk intelligently on technical topics, to know how certain pieces of work should be done, to be able to do the work if required, and to recognize good work, and be able to test for it. No technical school has the time to teach everything thoroughly. It is the common complaint of some without a technical education themselves, that the technical schools do not in four years impart to the high-school boy a full and complete knowledge of all the principles, practices, and wrinkles of steam, hydraulic, gas, pneumatic, and refrigerating engineering, and make of him an expert machinist as well.

The story of the professor and the commutator can doubtless be matched many times over; but as the academic college has notoriously failed to teach its students common sense, I know of no reason why the engineering college should be held up to ridicule if it does not succeed in imparting engineering sense to those, either in faculty or student body, who are absolutely devoid of it. The question has been frequently asked of late if the engineering colleges were not turning out more graduates than the community needed, and if it would not be better to decrease the quantity and improve the quality, and remand the balance to courses of study more suited to their personalities and mental abilities. But so long as there is the present lively and unfilled demand for the technically trained graduates of our engineering colleges, it would seem as if the colleges were of some use in the world, even if they have not multiplied their courses as numerously as some enthusiasts would desire, and spread their meagre incomes over an ever-broadening field.

In the "proposed solution," "it is proposed to train every pupil in a general knowledge and practice of pattern making and foundry moulding." The engineering schools at present not only do this, but also do the same in blacksmithing, tool dressing, and foundry melting. They try to do as much for one

of the engineering trades as for another in proportion to its relative importance in engineering construction. In the proposed solution, upwards of 2,600 hours are to be devoted to shop work, in comparison with an average of something like 450 hours, which are at present devoted to this work in the engineering colleges. Worcester Polytechnic Institute has a total of only 1,559 hours of shop work in its mechanical engineering course, which is much in excess of the majority of the best schools. The proposed scheme adds at least 70 per cent. to the time allotted to shop work in the Worcester schedule and 500 per cent. to that of the average engineering college. This would seem to be an abnormal development of the machine-shop side, at the expense of the other engineering trades and of the science and culture studies. The illustration taken from the medical schools is exactly the practice of the engineering schools of to-day. The embryo surgeons "do play at hospital practice"; and not until they are graduated and become internes do they have the chance to perform real operations and save real lives. In the engineering schools the young man is drilled in the anatomy of the machine in the drawing-room; dissects it in the shop, studying its muscles and vertebræ and nervous system; causes in the blacksmith shop new flesh of iron to grow up in the wounded members so as not to leave more than a scar; knits broken bones together in the flasks of the foundry; and not only repairs old bodies, but actually makes and shapes new engineering beings in the foundry and machine shop, and all with his own hands. Furthermore, he visits other shops or hospitals to see how others do it, and like his medical brother, he does not become chief surgeon or even house surgeon in managing an engineering hospital until, after months of practice as interne after graduation, he learns by experience to carry increased burdens and to be solely responsible for the lives of his patients, who are the users of the machinery designed and constructed by him. Visits to the scrap heaps of the schools will convince the most sceptical that not only has a great deal of dissecting been done, but that there is a Potter's Field as well.

The students of our engineering schools do get remunerative employment, not only immediately after graduation, but also during their summer vacation. Such inducements are sometimes held out to young men who have completed their sophomore year to remain with their summer employers as draughtsmen

and designers, that the schools frequently lose from their rolls the name of a promising young man on account of the flattering offer which he has accepted. Nor must it be forgotten that our most successful instructors have had broad and practical experience in the works, as a rule.

The author of the paper not only omits to give us any details of what studies he would retain in the other half of the Half-time Schools, but he also relieves the student of "any anxiety about lessons" from Monday noon until Tuesday noon. May we express the hope that the author will add a curriculum of the literary studies which in his judgment a half-time but liberally educated machinist will require. Applying the proposition to a course of study such as is found in the Columbus High Schools, I find that in the half-time allotted to book work of the 71 hours per week now divided among the four years, there would possibly be room for the 17 hours in English, the 4 hours in United States history and civil government, and the 14 hours in mathematics—from arithmetic, through algebra, plane and solid geometry, and plane trigonometry. The 8 hours of ancient and modern history, the 18 hours of foreign languages, physical geography, and all scientific subjects would have to be omitted. Possibly some of the English might profitably be replaced by physics. But when would a young man get time to prepare himself for the two recitations on Tuesday afternoon, to write his exercise in English and to work his examples, after having been in the shop or at recreation since he left the class-room on Monday morning? Writing from the point of view of New England and its technical schools, with their usually high fees and its expensive living, the author possibly is not familiar with boys such as we find them west of the Alleghenies, many of whom come from poor homes where work, stimulated effort, and self-denial have ingrafted in them a desire to take advantage of the free tuition of the State universities; who work in the shop or in the field through the summer to earn at least a part of the money which they spend during the winter in getting a technical education of one kind or another, and who either borrow the balance of the $150 to $225 that may be needed to pay all the expenses of living comfortably, or else eke it out by jobs picked up from week to week during the college year. In this day of popular free education, the advantages of college training is out of the reach of no one who has the deter-

mination and pluck to earn them and the mental ability and energy to get them. Some of the keenest intellects and some of the most successful business men and some of the ablest engineers of New York and New England to-day got their start in life by their own efforts, nurtured and trained in the universities of the West. Young men of this kind cannot be held down, neither do they want just those subjects which will enable them to earn a little higher wage; they want as good as there is to be obtained. Neither are they afraid of the bugaboo of examinations, as they have learned that every day brings examinations to them in one branch of knowledge if not in another.

As to the commercial side, I think it will be admitted that manufacturers are much more inclined to assist the engineering schools than they once were. They do not like unfair and unequal competition; but several have expressed their willingness to buy from the schools those castings and finished parts which will bear inspection, and which they can use, and have urged upon the schools the desirability of increasing their incomes in this way. In the best schools it will be found that practical shop work advances the student along the lines of both instruction and construction. With the latter system comes the temptation to the instructor to avail himself of the skill and inherent ability of the better boy and to give the poorer mechanic a job which he can complete successfully. I regret to say that observations and experiences reaching back some twelve years prevent me from agreeing with Professor Higgins that the probability is that in the commercial Half-time School everything from first to last will be made subservient to the interest of and entirely for the best and highest educational advantages of the student.

Experience teaches that in the workshop run for educational purposes student labor is never financially profitable; and when it is profitable to the shop it is with serious loss of time to the student, and means that he has been kept making some piece continuously after he has learned how to make it successfully, and that he has been robbed of his chance to learn and to advance. In this, as in many other things, to "keep to the middle of the road" is not always the easiest path. I do not think, therefore, it can be urged that a commercial Half-time School can be made "more than self-supporting without an income from its endowment fund."

The author draws attention incidentally to the fact that our public school system of education does not train boys and girls for any special occupation or avocation in life. It is for this reason that many boys and some girls drop out and go to work, because the curriculum of the high school seems to them to offer nothing of special interest, and which, in their opinion, will fit them the better to wage the battle of life and prepare for old age. It was to fill this need that manual training was introduced into some schools, and it seems that wherever it has been in charge of practical men, rather than of dreamy theorists, there it has succeeded. In some of our larger cities, trade schools are doing most excellent work in the practical instruction of the artisan; but they flourish because they give to their students a training which has a money value, and does not prevent them from being wage-earners at the same time. On the other hand, the object of the system of public education is to make more capable and better citizens, and not solely to teach a boy how he can earn big wages, or to supply the needs of manufacturers for skilled artisans. If the day of the Half-time School should ever come, I hope that the trades of plumbing and of domestic service will not be forgotten. Until then we should rely upon, foster, and advance our kindergarten schools, our manual-training high schools, and our trade schools, and not forget that our technical schools, both public and private, could do more and better work if more generously equipped and endowed.

Prof. C. B. Richards.—Such a scheme as Mr. Higgins advocates, which should provide for even a greater proportion of the time to be devoted to shop work than he provides for, would, I fully believe, give excellent results in turning out well-trained, skilled young mechanics—that is, skilled to the extent that a good apprentice becomes skilled—who would be equipped with sufficient fundamental knowledge of the principles of mathematical and physical science and of proper methods of observation and study to enable them to make useful men of themselves after a *comparatively* short experience outside the school.

A vital feature of the scheme is that which relates to the manner in which the shop practice shall be conducted; that it should be directed to the production of a high grade of salable product, and that the organization and methods of administering the shops shall be, in effect, the same as for a well-con-

ducted high-grade shop which is run for the purpose of turning out a first-class article at a good profit.

I do not believe that any other kind of shop practice for a student is worth what it costs the institution he studies in or the student himself.

Prof. J. B. Johnson.—For the past two years I have been studying the organization and methods of the various classes of industrial schools in Europe, and have recently spent several months in examining them. I am entirely convinced that some means must be found for giving to our industrial workers in the shops and offices a greater theoretical and practical training. The education given to young men in our higher technical schools carries them away from actual practice along industrial lines rather than into such practice. When they have completed their college training they are usually not disposed to seek employment as apprentices in our manufacturing establishments, and hence few of them ever learn such a business sufficiently well to become foremen, superintendents, and general managers of such business. As a matter of fact the graduates of our manual training schools seem to be better fitted for these employments than the graduates of the engineering schools, because they are more ready to accept humble positions which will enable them to thoroughly master the details of the business. At the same time these young men are not sufficiently educated theoretically to make them valuable directors of any line of manufacturing or other industrial enterprise in which a thorough scientific training is required. They succeed in these lines rather because of the absence of any better material than because they are specifically qualified for the places. I believe, however, the Half-time Schools proposed by Mr. Higgins will come nearer meeting the American demand for higher trained practitioners and directors of mechanical enterprise than any other with which I am acquainted. Its inexpensiveness, also, owing to the possible profitable returns, further commends it to our public school boards and to private benefaction. I also know of no better person to organize such a school than the writer of the paper, and I, therefore, sincerely hope that he will find the means very soon for organizing and equipping one or more such schools under favorable conditions. The success of such a school would depend almost wholly upon the management, and therefore it is important that the first ones should be wisely

administered. In this effort to arouse public interest in the more efficient kind of education for artisans, I trust Mr. Higgins will have the cordial and hearty support of the entire membership of the American Society of Mechanical Engineers.

Prof. Charles L. Griffin.—All machinists, foremen, draughtsmen, and mechanical engineers have a common fundamental quality. With the widest variation in experience, excellence, peculiar skill, or traits of character, there still may be traced a fundamental habit or line of action common to all. This habit is the power of thinking in a mechanical way; of sifting through the meshes of a fine mechanical brain the evidence and facts pertaining to the problem at hand. This is a cultivated habit. Even the mechanic born to his trade has to train himself in this respect, only he cultivates the habit more easily than the others.

If, then, the power of thinking mechanically be the essential of the mechanic, it should constantly be impressed upon the student as the prime essential in all applied work.

Mr. Higgins says: "To be a thorough mechanic, which he ought to be before he can be a well-trained engineer, he must be able to do the work, and this the present technical school does not teach thoroughly." I cannot believe that this is quite true. The words say that mere manual dexterity is the indispensable article. I do not think Mr. Higgins means quite that. True proficiency is not attained by the mere doing of a thing. It is "how you do it" which tells the story, and "how you do it" depends, not upon your hands, but upon your head. True proficiency is the indirect result of a state of mind, and mechanical proficiency in any department of the art must be based on a mechanical state of mind. The machinist does not rise to be a foreman because of his manual dexterity, but because he has developed his power of mechanical thought to a higher degree than his fellows. The two are, however, to some extent coexistent. I do not believe that a man can snag castings properly unless he be possessed of a degree of mechanical thought. A hole cannot be drilled in a piece of cast iron without some judgment as to the rate of feed, the lubrication or non-lubrication of the drill-point, danger of clogging and breaking the drill. Success in any branch of the trade, from the lowest up to the design of machinery of the highest complication, depends on the acquirement of the same quality.

The technical school often does not teach practical work

thoroughly at present, and it never will just as long as the cramming process enters into the applied work. The tendency of the technical school is to teach subjects, not principles; to make it appear by the catalogue that its students study a great variety of branches of engineering, and that the graduates are past masters in the specialties of the art. This forces upon the student the idea that each branch of engineering has a separate basis; that he is to study steam-engine design and finish it; then take up locomotive design and finish that; then pursue a special course in machine tools to a finish. Now while each of these has its peculiar conditions which influence its design, they are all dependent upon fixed mechanical principles for their successful operation, and should be approached by the student from a common fundamental standpoint. The true mechanic must build his theories and weigh his evidence and facts by his mechanical sense alone. He never finds his daily problems duplicated. Each one calls for his best mechanical thought. The student must not be specifically taught to build a steam engine, a locomotive, or an engine lathe, but to build a *mechanical machine* for the purpose required.

It has been my privilege for nearly a decade to supervise the work of college men and others in a manufacturing establishment, chiefly on drawing-room work. For a limited period I have also partaken in the education of engineering students in applied work. In both cases one of the most serious weaknesses I have had to contend with has been the lack of ability to take hold of work, to know how to start on a new problem, to plan a method of attack. This is the result of the failure of the men to realize that they must do what every engineer has to do, viz., *think*, think mechanically. When they do finally realize it they make good students and good engineers. When an apprentice learns to think about his work he begins to be a machinist.

I believe engineering should be taught as a state of mind, not as an abstract science like mathematics and the languages. From the start in Mr. Higgins's Half-time School, up to the highest grade of college engineering education, the habit of mechanical thought should not merely be implied, or left to develop by itself, but should be forced upon the student at every turn of his work in the lathe, and at every problem he has to solve in the class-room or over the drawing board.

Mr. Percy A. Sanguinetti.—On account of some adverse criti-

cism of manual training schools, which has been brought out in the discussion of Mr. Higgins's paper, I feel that I ought to relate my experience about the North East Manual Training School of Philadelphia. I am personally acquainted with many of the graduates, who are earning from eight to twelve dollars a week, which they obtained immediately after leaving the school. One of them is in the drawing office of the Baldwin Locomotive Works, and his wages have recently been increased.

I have visited the school, and know the class of instruction that is given there, and am acquainted with many of the professors and teachers.

A graduate of the school is eligible to admission to the University of Pennsylvania without examination, and I know of a case where a graduate was admitted to a university in another city without examination on certain subjects which the boy's papers and notes showed he had made satisfactory progress.

I think that a boy of average ability and application could earn a fair living from the instruction that the North East Manual Training School of Philadelphia affords, should he be unable to obtain any further training, and I feel pleasure in making the statement.

Mr. William A. Lorenz.—Mr. Higgins's paper has been very thoroughly discussed, and there may be very little room to say anything that is useful. But the subject seems so important that it should be encouraged by all suggestions that will help the project along.

The best way to start an enterprise which meets opposition is to remove the opposition, or else to start without causing opposition. The Half-time School which employs skilled labor, and a large proportion of unpaid boys, who are practically apprentices, is bound to meet with a great deal of opposition from several classes. These classes are the tax-payers, who are to give their sanction to the establishment of such a shop; also the labor unions, who will wish to control such shops as union shops; also the established manufacturers, who will claim that they cannot compete with shops which employ a large number of unpaid workmen, namely, the boys. It seems to me that most of the opposition from these classes will be removed by providing that the Half-time School shall pay wages to its apprentices, as is usual in commercial shops, and this plan of paying will provide an extra inducement to those entering such a school shop.

non-technical mechanics do not always reason and theorize correctly, and it is from that cause that the old saying, that such and such "may be all right in theory, but it will not work in practice," has arisen. Now I believe there is less and less of this erroneous assumption as time rolls by, and as more and more of our technical men get into business and authority.

Now, regarding Mr. Higgins's paper, I must agree with him in his desire to furnish more competent practical men for our shops and engineering professions; that these young men when they leave their schools and engage in practical engineering and mechanical work are not what we expect them to be, and in many cases prove a disappointment to themselves, is a fact much to be regretted. In the first place we possibly expect too much, and on the other hand they assume too much, the result being a disappointment all round.

I have said all I feel justified in saying about the methods in the schools, but to the student I want to say this, that when you have finished your three or four years' course in the technical school just stop a minute and pinch yourself to first realize whether you are wide awake or not, and if you find you are, then put on your overalls and spend the next three years in some shop learning how to make use of the training you have subjected yourself to the last three years by going to work at seven in the morning and quitting at six at night, and if you can do that, and do it with a good grace, then you are the right stuff and are wanted for machinist, foreman, superintendent, or some other position that will give you good remuneration and an influence in the community. If, on the other hand, these last three years of your apprenticeship pall on you and you cannot stick them out, it is better to be found out at this stage of the game and save you or some employer from final disappointment.

Mr. Higgins makes many "pat" remarks in his paper, and in some parts, I think, speaks of the surgeon who had been so carefully educated that he knew just how a delicate operation should be performed, but could not perform it himself. I think we would all agree that we would never think of employing such a man to cut off a leg or amputate even a finger. I believe this can be just as properly applied to the mechanic, and if I should offer a criticism to our technical school course it would be to discard this theory, that I believe to be pretty general in most technical schools, that it is not thought necessary to be able

actually to do the various kinds of mechanical work, but simply to know how it should be done. The grave question in my mind is, How do you know how it should be done if you cannot do it? I say you do not in ninety-nine cases in a hundred.

Now, as to attaining the end sought by Mr. Higgins, I cannot agree with him that the time he proposes to devote to a full course in his "Half-time School" will be sufficient fully to equip a young man; further, I do believe that our technical night schools will and do accomplish the end sought, and that when a young man has served his three or four years' shop apprenticeship and at the same time has had a three years' course in a good night technical school, he will be better equipped to fill the position of machinist, foreman, superintendent, and engineer than is possible in a Half-time School, taking the same number of years. Also that the boy who has the ambition and pluck to grind out three, or, in many cases, four years, in the way I suggest is made of the right stuff, and he is wanted, as I said before, to fill just the positions mentioned.

The boy who starts in the shop before becoming inoculated with technical school atmosphere will, in my opinion, find himself in a more appreciable mood than he will if he finishes a technical course at twenty or twenty-one years of age and then tries to round up his schooling in some shop.

In the technical night school the problems presented are of a particularly practical nature, and deal directly with the familiar problems met with during the day in the shop, the reasoning out of which appeals to the appreciable mind of the boy in a manner and with a force that cannot be obtained by a course in the Half-time School as proposed. The nearest approach to it would be to make the half-time course six years, and even with that extended time I am of the opinion that the shop practice to which the boy would be subjected would not meet the shop practice of the several machine shops of a community. This I feel would arise from several courses, one of which would be the difference in shop discipline and business requirements.

Prof. C. L. Weil.—I have been led to suspect through this discussion that there may be some difficulty in respect to the "*organic* function" of the technical school. I only wish to speak—from the teacher's side—of one point. The author of the paper proposes—I will not say the author proposes, but those who have criticised the paper seem to think that he pro-

poses—to supply a class of men to fulfil a particular function. Now, from the teacher's standpoint, the very interesting question is, How are you going to catch your rabbit? How do you know your man? How can you pick the man at this time for said place? That is the interesting point to us.

Mr. H. Wade Hibbard.—In general, I approve most heartily of Mr. Higgins's ideas. Having learned my machinist trade in a locomotive contract shop, with its hustling methods, I have regretted that students in technical schools do not learn hustling shop methods in the school shops. Mr. Higgins's commercial school shop would remedy that; and even if a school shop were not to become commercial, its methods would be greatly improved by putting at its head a machinist who had been a foreman in a contract shop famous for underselling its competitors, and yet making good machinery. The difference between the ordinary school shop and the commercial shop is like the difference between the contract shop and the railway repair shop. I advise all students taking my work to go into summer shop work; contract shops if they have decided to follow railroading after Sibley.

For the future railroad man the contract shop teaches variety and excellencies in new designs, piece-work cheapness, inspection cares, labor-saving appliances, modern quick methods, "hustle." At the last convention of the Association of American Railway Master Mechanics and Superintendents of Motive Power —the keynote of which, from presidential opening address to evening illustrated lecture, seemed to be the technical graduate in the motive-power department—the thought was presented that he (the graduate) should be of use also in introducing contract-shop methods into railway shops. This was taken up by the railway technical press and emphasized. The usefulness is apparent. The railway-shop foreman is not brought into such intense competition with a rival concern, and is not spurred into latest cost-saving schemes. He runs his bolt headers too slowly, does not insist on record-breaking planer cuts, thinks he must do as the fathers have done. The higher officials are seeing that these notions must be changed by the infusion of new blood. The technical graduate is unhampered by tradition, and is trained to use his eyes, ears, and judgment to learn the best that is doing everywhere; careful, in applying the new, to be conservative.

In fact, I believe that every mechanical engineering student should spend his summers in commercial shops. This will enable students, after three years or less of theoretical study in the recitation-room, and a valuable though short period in the educational shops of the college, to become acquainted with the rapid commercial methods of the piece-work contract shop; or with the slower, though in some respects the more interesting and instructive, railway locomotive repair shop. It is a distinct gain to have made this personal acquaintance with commercial steam engineering and the economics of manufacturing practice in the midst of the college course. The remaining portion of any course will be found more profitable. The practical bearings of theories, problems, and designs will become much clearer. The student advances faster than his fellows and profits more in lecture and designing. The better positions after graduation are also more easily secured by those who have had even this limited commercial shop experience.

Contrary to Mr. Higgins's statement, which I am inclined to believe is the idea of most mechanical seniors, viz., that they will step out of the engineering school into "good positions," railway mechanical seniors become thoroughly imbued with the hope of getting into a railway shop at a dollar a day to learn the machinist's trade, expecting by their education and ability to rise very much faster than other shop young men who have not had the advantages of a technical school. Some will grow up to be gang bosses, some on to be shop foremen, some on to be road foremen of engines, a few to rise to be division master mechanics, occasionally some to become superintendents of motive power, and on beyond. It is of course true that the shop foreman will have no use for his hard-earned mechanics of engineering as a tool, and his past efforts will thus have been, in a measure, wasted. Yet that subject gave him entrance to later subjects, gave him discipline of mind, and placed him on the road to the highest achievements.

Of Mr. Higgins's desire for schools with "education complete at each stage" from the grammar school up, I can most heartily say that I hope it will be realized.

Prof. L. S. Randolph.—The paper is an exceedingly valuable one, and while fully realizing the importance of the subject and agreeing with the author in the main, there are certain points which will admit of discussion, to say the least.

First. The position of a foreman is justly considered a difficult one to fill; but not for the reason which the author intimates, namely, that there should be great mechanical skill. There is a proverb in the shops that the best mechanics usually make the worst foremen. The ability to manage men, make decisions accurately and promptly, or, in other words, good plain business or executive ability, is of far more importance than great mechanical skill. In one case a young man who had failed to graduate at one of our technical colleges, and who would have come under the author's class of discarded material, after a year's apprenticeship succeeded to the general foremanship of a large railroad repair shop, making a much better officer than his predecessor, who was a skilled mechanic. This is not the only instance which has been observed. Those qualities which are so necessary to the success of a foreman are not developed in our technical schools unless perhaps on the football or baseball field.

Second. In regard to the falling off in the number of engineering students during the period from 1894 to 1897, was there not a corresponding falling off in the total number of students? In several colleges which were observed at that time there was a falling off in the number of students of about that ratio, viz., 15 per cent. In one institution there has been an increase of engineering students of about 10 per cent. in the last year. While doubting the figures as given, no one who investigates the subject carefully will deny that we must have a reduction in the number of engineering students in the near future, or some new outlet must be procured for them.

Third. The criticism which the author makes that in many of our schools the tendency is to make scientists and not engineers is undoubtedly true in far too many of them. The idea is to give the student great facility with equations and the ability to solve problems in kinematics, etc., of great intricacy and uselessness, without attempting to show him that a great many of the constants, etc., are far more difficult to determine than the final result of the equation would be when determined some other way; or that the problems in kinematics, etc., are seldom if ever applied. In too many cases the guiding principles in selecting teachers seem to be the same which would actuate the man who would select for a swimming teacher one who had never been near the water.

If there is any dearth of skilled mechanics it is due rather to

the neglect of the manufacturers to train them. A boy serving his apprenticeship is too frequently put on one machine and kept there, if not for all, for the greater portion of his time. We have planer and lathe hands, but few machinists. Many complaints have been made that there is no demand for the machinist or the tradesman; that when the machine hand is needed a laboring man and not a journeyman is put on the machine and trained to run that machine. The whole tendency of modern manufacturing seems to be to so organize and equip that skilled labor is not needed, or to reduce the demand for it to a minimum. Half-time or part-time schools have been tried, and in one case, notably that established by the Baltimore and Ohio Railroad at Baltimore, seemed to fail. What the cause of the failure was remains in doubt. One reason assigned, namely, that the boy, after five or six hours of manual labor, was not in a position to study, was, from the writer's experience, well taken. The night schools in our large cities and the correspondence schools, particularly the latter, give to the boy who has the mental capacity and the will to study all that he needs in the way of education to be a first-class mechanic.

That the shops for instruction purposes in our large technical schools should be operated as commercial shops is unquestionably correct, but the details and the expediency of the step are too great a problem to be entered into here after the excellent presentation of the subject by the author. It would seem that the original shops were organized for the purpose of training the hand only. The author seems to think that they should train the head also, or, in other words, do both at the same time. That this can be done a careful study of the subject will convince the most sceptical. The objection which has been urged so frequently to the organization of the shops on a commercial basis is that it is not expedient from a financial point of view. The figures given by the author go far towards negativing this argument.

Mr. William Barclay Parsons.—This question of the proper education of an engineer is one that I have taken a great interest in, not only from the point of view of the practising engineer, and therefore requiring assistants, but also from the point of view of a trustee of one of our largest universities.

The views which are expressed by the author are those which have been urged from time to time, but in different forms, as

against what is erroneously called theoretical training; and, although the author states that he is more particularly interested in the education of the machinist, he nevertheless falls into the error that most people do, in failing to differentiate between the machinist and the engineer; and perhaps this is as well illustrated in his anecdote of the professor and the two rings as in any other part of his very able paper. The engineer would regard the making of that ring as involving (1) the mechanical principles involved; and (2) their application through the machine in which it is to be used. In other words, he considers as paramount the design and engineering features involved. The machinist, on the other hand, looks at it entirely from the view-point of the shop—how it is to be made and what it is to cost. Here we have before us at once two different men looking at problems from different points of view, and whose education, like their mental attitude, must consequently be different.

The whole argument, through Mr. Higgins's paper, is written from the standpoint of the machinist and shop practice. The trouble with our technical colleges has been that they have endeavored to educate both types of men, and, like most compromises, this idea has been a failure.

In the study of the number of students in our technical colleges I discovered—and I admit to my surprise—that the number of students had decreased. This is due largely to the fact that at the principal colleges the requirements for admission have in recent years been raised, and that, therefore, they have practically closed their doors to a large number of young men whose idea is to become machinists.

When examining the details of the subject, I furthermore discovered that the only two institutions in Eastern colleges where the number of students in the engineering courses has shown a continuous and unbroken increase from year to year are Columbia and Harvard—the two institutions which, above all others, aim to give a high-standard engineering course, and which make no attempt to turn out machinists only. If, therefore, Mr. Higgins points to this falling off as an argument on his side, I think he is mistaken; the lesson is the other way.

Speaking from the view-point of practical experience, as I see it, I take it that there are needed specialists, men trained for a given object; and this applies to machinists as well as to en-

gineers, and it is, I contend, impossible to educate them both in the same institution. To organize Half-time Schools, as the author proposes, would therefore be working on this line, as he would aim thereby to turn out machinists. Such schools, however, are not to be confounded at all with the technical college, whose place they cannot take. The ordinary technical school, when it tries to occupy a middle ground, fails, and it therefore seeks to work towards a higher level, as Mr. Higgins points out, and finally becomes another technical college.

Professor Higgins.—An unexpected event occurred, which I think you will agree with me is a fortunate event, at the beginning of this session. This paper contains results of my thought and observation upon this subject for the past twenty-five years, and I treated it as fully as I could in a paper limited as such a paper as this must be. Notwithstanding that, I naturally enough prepared an abstract that would probably have taken me half an hour to read to you, and I do not think it could have added very much to what I have written already, certainly as compared with the interesting and valuable suggestions that have come from the discussion. I had this half-hour sermon prepared, and entered a crowded car, and when I got out it was lost. When I came in at a late hour, the trolley car having been detained for a time, I concluded that the event was a very fortunate one, and I think so now.

I have been exceedingly interested in what I have heard, and I am gratified at this, that all the adverse observations upon this paper have come, I believe, from a miscomprehension of the facts in the case. For instance, remarks have been made repeatedly about a school depending upon dividends of the school shop. Now I do not think I have given that idea in the paper at all. At any rate, it is not my idea. I do not think it is necessary to depend upon any dividend of the school shop. I simply stated the fact in this one instance where I have had the best opportunity to observe what could be done, and I tried to make it clear there that dividends, or commercial success, were not the leading object of the school at Worcester. The students are there for what they can learn and not for what they can earn, and their interests are first always. I exhibited those figures, and I adhere to the fact which those figures are intended to show, namely, that if a school shop is well conducted, whose sole purpose is instruction and education, it must neces-

sarily be conducted along lines that other good shops are conducted upon, and you must have the same management, and the same kind of ability and skill and method for producing, that the other good shops have. Otherwise, when the graduates go out they have got something to unlearn and something to learn. My point is that if a shop is well conducted, its success is inevitable from the nature of the work.

Another criticism is this, that the management of the school shop is unusually difficult. Now, nothing more depends on the management of a school shop than on the management of any other shop. I want to submit it to you, gentlemen, if there is any reason under the heavens why a school shop where large moneys are invested and the interests of a large number of men are at stake—why a school shop should not be managed well, and why we should not have teachers and instructors and mechanics that are capable of doing it? Generally the only way of getting men capable of doing a thing well is to pay them as much as they are paid elsewhere. I am out of the school business, so I can speak of this without reserve. I think that our technical schools ought to have for the instructors the best machinists, the best machine designers, the best engineers, the best draughtsmen, and the best and most cultured gentlemen that America affords, regardless of what it costs. They can afford to have the best, because they will pay best, and they will turn out the best graduates. That is what we argue when we are running a shop of any kind. Several gentlemen have been troubled with the idea of the difficulty of combining the common school and the shop. There is no great difficulty in combining them, because about all the combination that is necessary is just about the combination that we used to have in the old-fashioned district school, where a boy got up and did his work in the morning before he went to school, and did his work again after he returned from school. Now, all we ask of a high school, any public school, is to so arrange, if they will, the hour-plan so that this shop, that is just as independent of the public school as any other shop in the State, can carry on its work with advantage in combination with their hour-plan, and the shop is conducted by a corporation chartered to do just exactly what the corporation wants to do—to educate young men; and that gets away with the only serious difficulty that has ever obtained against a commercially productive school machine shop, namely, the com-

plaint of competitors. Now, if a shop is organized and chartered to do just that sort of thing, there is nothing in the world to prevent them from doing it, and the complaints that a competitor may make will have nothing to do with it. The only serious objection to commercial shops is that generally the management of technical schools object to subjecting their products to the test of the open market, and I do not know of any other way to get over that difficulty unless you change the management. (Laughter.)

Now, there is one thing more and I will close. This matter of culture and mental discipline I am very much interested in, because I believe that there is more opportunity for a higher grade of instruction in a school machine shop than has ever been recognized by professors. I think that much more—and this is the point that I want to make—that much more, very much more, than manual training can be successfully taught in a machine shop. It seems to me that the shop lecture-room is an important idea, and that the shop lecture-room may be as productive of good in many ways as any lecture-room in Yale or Harvard or Columbia. The conditions are all in favor of the machine-shop lecture-room, because when a pupil needs to know a thing and wants to know a thing, that is the best time to teach him. I believe that manual skill—I agree with these other gentlemen—is only a very small part of an education. I believe that all sciences can be successfully taught, and perhaps with more advantage, in a machine shop, and that everything that is desirable in character in young men, including culture, can be developed in a machine shop and in its lecture-room, provided you have as good teachers.*

* NOTE.—The great interest and importance of this subject induced the Publication Committee to direct that it should be continued as a topic at a succeeding meeting. The continuation will therefore be found among the papers of the Cincinnati meeting, and its location determined from the Index reference.

PAPERS

OF THE

CINCINNATI MEETING

(XLIst)

MAY 15th TO MAY 18th, 1900.

PAPERS

OF THE

CINCINNATI MEETING

(XLIst)

MAY 15th TO MAY 18th, 1900.

No. 852.

PROCEEDINGS

OF THE

CINCINNATI MEETING

(XLIst)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

May 15th to May 18th, 1900.

LOCAL COMMITTEE.

JAS. B. STANWOOD,	JAS. R. MAXWELL,
WM. H. DOANE,	HENRY MARX,
HARRY M. LANE,	WM. H. BIXBY,
JAS. C. HOBART,	WM. CORRY,
E. B. JOHNSTON,	A. E. KNECHT,
THOS. G. SMITH,	GEO. W. GALBRAITH,
H. M. NORRIS,	CHAS. F. KOCH,
GEO. A. GRAY,	ERNST RICHTER,
WALTER LAIDLAW,	ARCHIBALD W. BLAIR,
WM. LODGE,	S. L. MOYER,
CARL F. LUNKENHEIMER,	F. F. NICKEL,

BERT L. BALDWIN.

IT will be remembered that the city of Cincinnati had presented to the Society and its Council a most emphatic and earnest invitation to hold the spring meeting of 1899 in their city, and that the selection of Washington with its great attractions for the meeting of that year had compelled the wish of Cincinnati to be postponed. It was, therefore, with great

pleasure that the Council acted favorably upon the proposition that the spring meeting of 1900 should fall to a district so full of mechanical interest as the southern part of Ohio and the city of Cincinnati.

The hotel headquarters and the convention room were selected by the local committee in the Grand Hotel on Fourth Street, corner Central Avenue, and the opening session was set down for the evening of Tuesday, May 14th. The meeting was called to order at half-past eight by Mr. James B. Stanwood, chairman of the local committee of arrangements, who in a few words of salutation introduced the Hon. Gustav Tafel, Mayor of the city of Cincinnati. His greeting referred to both the mechanical interests of his city and the residence growth of Cincinnati upon the surrounding hilltops. To the address of the Mayor, the President of the Society, Mr. Charles H. Morgan of Worcester, made brief reply, referring to the early introduction in this city of the automobile steam fire-engine, and to the changes which had taken place in the mechanical atmosphere of the country since his first visit, something like forty years ago. A social reunion, with music and collation, over which the ladies' local committee presided, was held in the parlors of the hotel at the close of the opening session.

Second Session. Wednesday Morning, May 15th.

President Morgan called the second session for the transaction of business to order at ten o'clock in the assembly hall.

The registration in the Society headquarters which has worked so satisfactorily in previous meetings was again carried out, whereby each line of the official signature book was numbered, and each convention badge bore the same number as the member's signature.

Reprints from the register were issued every day during the session, so that the members were kept posted as rapidly as possible concerning the arrivals and registrations at headquarters. The following members were in attendance, but the list does not include a large number of residents of the city, who by invitation of the local committee were made the guests of the Society for its convention during the stay in Cincinnati. A gratifying delegation of ladies was also present.

Aldrich, Wm. S.
Allison, Robt.
Ames, Wm. L.
Andrews, Wm. J.
Ashworth, A. K.
Baldwin, Bert L.
Barnes, Stuart J.
Barnes, W. H.
Bates, E. C.
Bixby, Wm. H.
Blair, Archibald W.
Blauvelt, W. H.
Bole, W. A.
Bonner, Wm. T.
Brown, Alex. T.
Brown, Chas. S.
Bryan, Wm. J.
Bulkley, H. W.
Burns, A. L.
Campbell, Gordon.
Cash, A. W.
Chamberlain, Paul M.
Cheney, W. L.
Cole, J. W.
Colvin, F. H.
Conant, H. J.
Corry, Wm.
Crocker, J. B.
Cullen, Jas. K.
Darley, E. C.
Davis, Chas. E.
Day, C. P.
Detrick, J. S.
Doane, Wm. H.
Donovan, Wm. F.
DuBrul, E. F.
Edwards, V. E.
Emory, F. L.
Farmer, Thos.
Fellows, E. R.
Follows, Geo. H.
Fernald, R. H.
Fingal, Chas. A.
Freeman, S. E.
French, Lester G.
Galbraith, Geo. W.
Garfield, L. M.
Gray, Geo. A.
Gray, Thos.
Grieves, E. W.
Gobeille, Jos. L.
Golden, M. J.
Goldsmith, N. O.
Goss, W. F. M.
Gould, W. V.
Hall, W. E.
Halsey, F. A.
Hannam, E. T.
Herschmann, Arthur.
Higgins, M. P.
Hobart, Jas. C.
Hoffman, J. D.
Hunt, Wm. F.
Hutton, F. R.
Jacobs, Ward S.
Jewett, F. N.
Johnston, E. B.
Johnson, Wm. T.
Katte, Edwin B.
Keller, E. E.
Kent, Wm.
Knecht, A. E.
Koch, Chas. F.
Ladd, Geo. T.
Laidlaw, Walter.
Lane, H. M.
Lewis, D. J., Jr.
Libby, S. H.
Lodge, Wm.
Louer, L. S.
Lunkenheimer, Carl F.
McFarland, W. M.
McGeorge, John.
Magruder, Wm. T.
Manning, H. G.
Marx, Henry.
Mason, H. I.
Maxwell, Jas. R.
Mesta, Geo.
Meyer, H. C., Jr.
Meier, E. D.
Miller, Alex.
Miller, E. A.
Miller, R. S.
Montgomery, H. M.
Morgan, Chas. H.
Moyer, S. L.
Nason, Carleton W.
Neff, E. H.
Neureuther, A. H.
Nickel, F. F.
Norris, H. M.
Paul, J. W.
Pilton, Wm.
Pollock, James.
Powell, E. H.
Porter, H. F. J.
Porterfield, H. A.
Reed, Henry S.
Reed, Saml. G.
Reiss, Geo. T.
Richter, Ernst.
Riggs, Jno. D.
Ritchie, Wm.
Rites, F. M.
Ritter, Henry
Roberts, T. H.
Rockwood, Geo. I.
Rohrer, A. L.
Royse, Daniel.
Sabin, A. H.
Schneble, R. G.
Schoenborn, W. E.
Smith, H. W.
Smith, Thos. G.
Stafford, B. E. D.
Stanwood, Jas. B.
Varney, Wm. W.
Wagner, Frank C.
Wallace, J. D.
Warner, W. R.
Ward, Chas.
White, H. S.
Widdicombe, R. A.
Wiley, Wm. H.
Willis, Edw. J.
Winther, C. A. G.
Yaryan, A. T.
Yawger, Edwin.

The first order of business for the convention was the reading of the report of the Tellers appointed by the Council to report

upon the election of members. This report was presented by the Secretary as follows:

REPORT OF TELLERS OF ELECTION.

The undersigned were appointed a Committee of the Council to act as Tellers of Election, under Article 14 of the Rules, to scrutinize and count the ballots cast for and against the candidates proposed for membership in their several grades in the American Society of Mechanical Engineers and seeking election before the forty-first meeting, Cincinnati, Ohio, 1900.

They have met upon the designated day in the house of the Society, and have proceeded to the discharge of their duty. They would certify, for formal insertion in the records of the Society, to the election of the following persons whose names appear on the appended list, in their several grades.

There were 483 votes cast on the blue ballot, of which 19 were thrown out because of informalities. The Tellers have considered a ballot as informal which was not endorsed with an autographic signature, or where the endorsement was made by a facsimile or other stamp.

GEO. RICHMOND,
JESSE M. SMITH,
STEVENSON TAYLOR,
} *Tellers of Election.*

AS MEMBERS.

Adams, Julius Le Roy.
Allen, Henry Asa.
Ball, Walter S.
Behrend, Ernst R.
Blauvelt, Wm. H.
Blencowe, John.
Burton, Frank H.
Chandler, Clarence A.
Dallett, Elijah.
Day, Ernest W.
Doebler, Chas. H.
DuBrul, Napoleon.
Enock, Donald.
Farrell, W. Elliston.
Foster, John M.
Frank, Geo. Wm.
Garrigues, Edmund.
Goldsmith, N. O.
Hannam, Edw. Thos.
Henshaw, Fredk. V.
Hill, Thomas.
Holbrook, Percy.
Holt, Frank E.
Kent, James M.
Keough, Wm. Thos.
Kuwada, Gumpei.
LeBlond, R. K.
Leibert, John.
Leland, S. D.
Lockett, A. M.
Lowell, J. Welch.
McKiever, Wm. H.
Mann, A. S.
Mershon, Ralph D.
Milliken, James.
Moseley, Alex. W.
Nevill, David Jack.
Norbom, John O.
Norcross, J. Arnold.
Norris, Almon E.
Orcutt, H. F. L.
Park, Franklin A.
Prellwitz, William.
Rider, George S.
Ritter, Henry.
Rowan, James.
Sammons, Elmer H.
Shantz, Oliver S.
Smith, Wm Edwd.
Snyder, Wm. E.
Sprapo, Ralph.
Stevens, John Edwd.
Stutz, Charles C.
Thornton, Wm. M.
Thuman, Frederic.
Tuska, Gustave R.
Tuttle, Willard S.
Ward, Chas. E.
Westcott, Arthur L.

PROMOTION TO FULL MEMBERSHIP.

Cromwell, J. C.
Darrin, D. H.
Goetze, Fredk. A.
Hewlett, Edwd. M.
Libby, Sam H.
Morgan, Paul B.
Preston, Geo. B.
Scholl, Julian S.
Scott, James B.
Winther, C. A. G.

PROMOTION TO ASSOCIATE MEMBERSHIP.

Smart, Richard Addison.
Wood, Albert C.

AS ASSOCIATES.

Briggs, Thos. H.
Crosby, Wm. W.
Du Brul, Ernest F.
Fernald, Robt. H.
Finney, John C.
Geier, Fredk. A.
Harmar, Josiah.
Herschmann, Arthur.
Hutchison, Richard.
Johnson, Theo. W.
Louer, Lewis Stern.
Mitchell, John H.
Reed, Henry S.
Salmon, Fredk. W.
Skinner, Samuel W.
Speed, Wm. S.
Thompson, Samuel K.

AS JUNIORS.

Arnold, Edwin E.
Astrom, J. I.
Bauer, Chas. L.
Boyer, Chas. W.
Brodhead, Alex. L.
Brush, Fredk. F.
Butler, Noble C., Jr.
Chandler, F. Fay.
Darbee, William.
Davis, Robert G.
Einfeldt, Chas. M.
Fuller, Jas. T.
Gamper, Herman.
Gannett, H. I.
Gingrich, Chas. S.
Goodman, William.
Grelle, Chas. Edwd.
Hall, Francis G., Jr.
Hannah, Fredk. A.
Heggem, Alfred Geo.
Hugo, Victor.
Inslee, Charles L.
Jefferies, Fredk. L.
Kaup, Wm. J.
Martin, Jackson J.
Morgan, Ralph L.
Ougham, Harry Rye.
Patitz, G. J.
Pryor, Frederick L.
Quigley, James Edw.
Robbins, Clarence C.
Rose, Edwd. E.
Sangster, Andrew.
Scheele, John M. B.
Sheldon, Samuel B.
Stegmann, Geo. H.
Thompson, Albert W.
Tower, Daniel W.
Tracy, Lyndon Sanford.
Wheeler, Harry E.
Whitney, M. L.
Wilson, Clarence C.
Wood, Edwd. R., Jr

The Secretary also read letters received in the morning mail, inviting the members of the Society to visit the public library of Cincinnati, and from Professor Thurston of Ithaca asking the members to interest themselves in the important congresses which were to be held in Paris during the International Exposition, having a scope substantially identical in character and purpose with those which were held in 1893 in Chicago. The Secretary referred also to the movement on foot in the Society to create a suitable memorial in New York City in commemoration of the work and achievements of Robert Fulton, and in further explanation of the work which has been undertaken by the Society as to a movement in the houses of Congress to give proper accom-

modation to the work of the United States Patent Office. In connection with the Robert Fulton memorial he reported the amount now in hand to have reached the sum of $1,369. No action seemed to be called for in connection with these two presentations, which were made for record.

The Chair then called for reports of professional committees. These reports were of progress and are presented herewith, and that on standards for direct-connected generating sets by its chairman, J. B. Stanwood, as follows:

Mr. J. B. Stanwood.—At the Washington meeting of the Society last May a committee of five was appointed to undertake the standardization of engines and dynamos as affecting those parts which are connected together.

While this committee has only had three meetings, yet a great amount of work has been done by correspondence, collecting data upon which to base its report. A circular letter was sent to all the leading engine builders of the country, requesting their advice upon certain points of prime importance to the committee. We have received very favorable replies from these concerns, and upon these replies to a great extent our report of to-day is based.

The three important points upon which we desired to secure information at the outset were:

First—The size or capacities of machines which should be standardized.

Second—The speeds at which these various sizes of machines should be operated.

Third—The diameter of armature bore for each different size machine.

The recommendations which have been received from engine builders have been remarkably uniform as regards these three points. This has materially simplified our work.

The committee is unanimously of the opinion that in order to secure practical results it should strive not for theoretical perfection but for a result which, while recommending thoroughly good practice, would at the same time coincide as far as possible with the practice of the greatest number of manufacturers.

The committee is also of the opinion that it was not desirable to have too many standard sizes, involving as such a course would the storage of a large number of patterns and carrying

large amounts of stock for both engine and dynamo builders. Obviously, too, the intervals between the sizes would be smaller for the smaller capacities, becoming greater as the capacities increased.

The sizes we have recommended as standard, stating them in the sizes of generators, are:

25 kilowatts.	75 kilowatts.	200 kilowatts.
35 "	100 "	250 "
50 "	150 "	

One of the members of the committee has had special experience in the manufacture of engines to match up with generators smaller than 25 kilowatts, and we had hoped to be able to embody in our report the result of his special investigation of these small sizes. Unfortunately, owing to domestic affliction, he has been prevented from sending his report in time, but we shall certainly have the benefit of it before our complete and formal report is presented, and possibly in time to distribute when this tentative report is put in print.

With respect to the matter of speeds for these standard sizes, we were guided by the principle already stated, of choosing those which so far as possible conform to the practice of existing manufacturers. We may say in passing that as two of the members of our committee represent two of the largest manufacturers of electrical machinery in the country, we have had the benefit in our investigation of a knowledge of what would suit the builders of generators as well as the builders of engines, so that in our recommendation we know that the speeds recommended do apply to a very large majority of the engines and generators which have thus far been turned out.

It will be observed in the table of speeds which we give that we have recommended an upper and lower limit for each size of generator and engine. The reason for this is that while the generator builders had already constructed machines for these extreme ranges, we found some of the engine builders tended rather to the lower and others rather to the upper limit. While in a very few cases some engine builders go slightly outside the limits, yet the limits recommended do cover nearly all the data which we have been able to collect.

STANDARDS PROPOSED FOR DIRECT-CURRENT DIRECT-CONNECTED ENGINES AND DYNAMOS.

Capacity in K.W.	Speeds in Revs. per Minute.	ARMATURE BORE IN INCHES.	
		For Center-crank Engine.	For Side-crank Engine.
25	300 to 325	4	4½
35	285 to 315	4	5½
50	270 to 300	4½	6½
75	250 to 280	5½	7½
100	250 to 275	6	8½
150	200 to 225	7	10
200	175 to 200	8	11
250	150 to 175	9	12

With respect to the subject of armature bores we were at once led to distinguish two classes of engines, designated commonly as "side crank" and "center crank." The members of the Society will at once understand the reason for the difference in the sizes of shafts for these two types of engines. In the very small sizes it will probably be found possible to use only a single size of bore, but for the standard sizes which we have above recommended we have found that engine builders practically insist upon two separate series of dimensions of shaft.

One of the members of the committee has made a special investigation of this subject and has secured the opinions of a large number of engine builders with respect to the sizes which would suit them, which enabled us to reach a conclusion quite readily.

If the sizes are laid out in a curve as may be shown on a diagram, it will be found that the curve is not a strictly fair one; the reason for this will be at once seen in the fact that we have recommended only whole and half inches, a practical feature, which we believe will commend itself at once.

We may say that our investigation of this subject has led us to believe that there seems to be a growing tendency in these combined units toward the side-crank type of engine.

There are several other important features of the committee's work in regard to armature size upon which we are not prepared to report at the present, such as the amount to be allowed for a pressing fit, nature of the fit, and some other questions. Before taking these up it is necessary to be sure that the line along which we have been working will meet with something like general approval from the members of the Society. If we find

that our work thus far meets with approval, we shall then be prepared to investigate these other subjects.

Practically the same statement as the foregoing applies to the sub-base dimensions for the support of the generators and the out-board bearings of shaft, owing to the different styles in which these are made.

As the members of the Society are perhaps aware, the American Institute of Electrical Engineers appointed a committee of their members to investigate this same subject from the side of the electrical builders, this having been done at the request of our Society after our own committee had been appointed. There has been one joint conference of the two committees, represented by a part of each committee, but this conference was at such a stage of the investigation that we were able to do little more than map out the general scheme of work to be pursued.

The Society will understand, of course, that the report which we now submit is entirely a tentative one and not at all in the shape, as regards corroborative documents, in which we expect to make it when our labors are complete. We have felt, however, as a year has elapsed since our appointment and as we have done a considerable amount of work, that the Society should be informed of it, both to know that its wishes were being carried out and, as indicated above, that it might express its approval or disapproval of the work we have done, so that our labors in the future may have the benefit of criticisms on this, a tentative report.

We believe that to secure the best results it would be well to authorize the printing of this preliminary report for distribution among members of the Society and among engine builders affected, in order to secure their views on what we have done.

Any individual criticisms or suggestions should be sent to Mr. J. B. Stanwood, Chairman of the Committee, 2927 Reading Road, Cincinnati.

The Secretary presented, on behalf of the executive committee of Junior Members conducting meetings at the Society's headquarters in New York, the report of the committee as follows:

REPORT OF JUNIOR COMMITTEE, MAY, 1900.

According to the general plan announced last spring the Junior Committee has, during the past winter, conducted a

series of monthly meetings, at the Society house, New York City.

The following are the subjects that were presented:

October 3.—"The Westinghouse Gas Engine," by Mr. H. E. Longwell, non-member, of the Westinghouse Machine Company. Attendance about 80.

November 7.—"Compound Locomotive Practice," by Mr. F. H. Colvin, then Junior Member, and associate editor of *Locomotive Engineering*. Attendance about 60.

January 2.—"The Present State of the Diesel Motor," by Mr. E. D. Meier, Senior Member, and chief engineer of the Diesel Motor Company. Attendance about 50.

February 6.—"Steel, Gun, and Gray Iron Castings, their Uses and Relative Values," by Mr. W. W. Bird, Senior Member, and Treasurer Broadway Iron Foundry Company. Attendance about 60.

March 7.—"Cylinder Proportions of Multicylinder Engines," by B. C. Ball, Junior Member of Ball & Corbett. Attendance about 80.

Each paper was followed by interesting discussion, and all but one were illustrated with lantern slides. In each case some two thirds of those present were Seniors.

It is worth noting that the announcements of the first meeting were sent to all the members of the Society, with the result that requests for Mr. Longwell's paper were received from Connecticut, Illinois, California, Ohio, and Louisiana. Thereafter, till the last meeting, notices were sent only to local members, with the result that practically no requests for papers were received. The last paper, however, was called for from Massachusetts, Louisiana, Indiana, Michigan, California, and New Jersey. This experience has determined the committee hereafter to send announcements to all members in the United States and Canada.

Of the above papers, Mr. Ball's was included by the Publication Committee in the regular *Transactions*. In any case each paper with its discussion is kept in the Junior file.

The opinion had been expressed that these meetings should be for Juniors only, or at least that there should be additional ones for Juniors only. Pursuant, therefore, to a suggestion of Mr. S. W. Baldwin, such a meeting was held early in this month, and the whole subject of the Junior movement was

thrashed out thoroughly by the dozen or so who put in an appearance. Through Mr. Baldwin's effort letters had been received from several of the ex-presidents of the Society, directing the attention of the Juniors to the opportunities offered by an active participation in the meetings, of extending their professional acquaintance and usefulness.

Discussion developed a common feeling that all grades of membership should be invited to all the meetings, and that announcements of them should be sent out generally, as before noted. In fact it was the opinion that every effort should be made to avoid grading or localizing the monthly meetings more than was absolutely necessary.

Therefore, during the coming winter the meetings will be held as heretofore, and the committee will lend its energies to the securing of papers and discussions that shall be distinct contributions to the subjects taken up. Under consideration at present are the following: The steam turbine, superheated steam, fuel gas, the methods of keeping shop records, individual motors in shop practice, pertinent subjects under engineering jurisprudence, etc.

A scheme of topical questions and answers is also being developed to supplement these meetings.

The committee has increased the membership to six, exclusive of Professor Hutton, by the election of Mr. T. S. Bailey and Mr. H. C. Meyer, Jr. At a recent meeting Mr. Meyer was chosen chairman, and Mr. F. E. Frothingham reëlected secretary for the ensuing winter.

The committee would like to say again that any and all suggestions or criticisms relative to its work will be gladly received by its secretary.

F. E. FROTHINGHAM,
Secretary Junior Committee.

The Secretary further added that the chairman of the committee for the next winter's work was to be Mr. Henry C. Meyer, Jr.

At the close of the committee reports letters were read by the Secretary from his Honor, David S. Rose, Mayor of the city of Milwaukee, Wis., and T. J. Sullivan, Secretary Business League, urging the consideration of Milwaukee as a place for the meeting of the Society in the spring of 1901. Two telegrams and

the confirming letters were on motion referred to the Council for consideration, with power. At this point invitation in the name of his associates was presented to the Society by Mr. A. L. Rohrer, that the city of Saratoga might receive similar consideration for the same meeting. Mr. Rohrer spoke as follows:

"It is the desire of myself and several members with whom I have spoken, that the desirability of the city of Saratoga should be considered by the Council in considering the question of a place for its spring meeting next year. There are quite a number of members of the Society in the neighborhood of Saratoga, which we would cause to include Schenectady, Troy, Albany, Mechanicsville, Cohoes, and other interesting points, and it will be, of course, unnecessary for me to call attention to the special advantages attaching to Saratoga as a convention city. The very large hotels of the city are able to take care of any number of visitors; it has many points of interest of its own; it is within reasonable distance of the New England members, and I feel sure that those who are engaged in the neighborhood of Saratoga would take pleasure in entertaining the visitors. We can arrange to have many pleasant excursions, and I am sure the members would be able to use their time in a profitable way."

This invitation was on motion similarly referred to the Council with power. Professional papers were then taken up, as follows: "Hot-water Heating from a Central Station," by H. T. Yaryan; "Systems of Efficiency of Electric Transmission in Factories and Mills," by Prof. W. S. Aldrich; "On the Value of a Horse-power," by George I. Rockwood; "Design of Speed Cones," by J. J. Guest. The following gentlemen took part in the discussion of these papers:

Messrs. F. N. Jewett, Daniel Royse, Carleton W. Nason, J. D. Wallace, Geo. I. Rockwood, Walter M. McFarland, John McGeorge, Edward J. Willis, Mr. Wesley, A. F. Nagle, W. F. Mattes, F. A. Waldron, D. C. Woodward, Saml. Webber, J. M. Smith, C. E. Barth, E. H. Lockwood, and C. H. Benjamin.

In connection with the paper of Mr. Rockwood, the Secretary reported action by the Council adverse to the proposition made at the New York meeting for the appointment of a committee to consider and report upon the question of the commercial value of a horse-power. It was the sense of the Council that under most circumstances this question should so much more properly be considered as being either a legal question, to be passed upon by a court, or a commercial question with which the Society might only indirectly concern itself, that their recommendation was adverse to the appointment of such a committee and that for this reason no action had been

taken. Mr. Rockwood in his debate presented the arguments in his opinion serving to rebut that conclusion, although in a most loyal spirit he concurred in the action which the Council had seen fit to take. The meeting then adjourned for an afternoon excursion, arranged by the Local Committee.

Reference to these excursions will be made in the conclusion of these proceedings.

THIRD SESSION. WEDNESDAY EVENING, MAY 16TH.

The professional papers of this session were as follows:

"Multiple-cylinder Engines," by Robt. H. Thurston; "The Gas Engine Hot-tube as an Ignition Timing Device," by Wm. T. Magruder; "Water-softening Plant of the Lorain Steel Company," by N. O. Goldsmith; "Education of Machinists, Foremen, and Mechanical Engineers," by M. P. Higgins. The participants in debate were Messrs. Geo. I. Rockwood, Professor Emory, Rudolph G. Schneble, E. W. Roberts, E. J. Willis, N. O. Goldsmith, Jno. McGeorge, Paul M. Chamberlain, E. B. Johnson, Wm. Kent, Wm. Lodge, Chas. E. Davis, Wm. T. Magruder, E. B. Katte, A. Sorge, Jr., A. A. Cary, and C. H. Benjamin.

At the close of the papers the President made announcement, under Article 31 of the Rules, that the following persons were to act as a nominating committee to present the names of candidates for office in the Society for the ensuing year. The names of the committee were:

Henry R. Towne, Stamford, Conn.
Jas. R. Maxwell, Cincinnati, Ohio.
Robert Forsyth, Chicago, Ill.
George I. Alden, Worcester, Mass.
Carleton W. Nason, New York City.

On motion the selection of the President was confirmed by the meeting and these gentlemen were duly constituted such committee.

The meeting then adjourned.

CLOSING SESSION. THURSDAY MORNING, MAY 17TH.

Professional papers were presented as follows:

"The Automobile Wagon for Heavy Duty," by Arthur Herschmann; "A Test of a Fifteen-million High-duty Pumping Engine at Grand Rapids, Michigan," by M. E. Cooley; "Tests

of the Snow Pumping Engine at the Riverside Station of the Indianapolis Water Company," by W. F. M. Goss; "Cylinder Proportions for Compound and Triple-expansion Engines," by B. C. Ball. Participants in debate were Messrs. Jas. R. Maxwell, Jno. McGeorge, T. H. Roberts, P. M. Chamberlain, Robt. Allison, Geo. I. Rockwood, Ernest F. DuBrul, F. C. Wagner, F. A. Halsey, F. L. Emory, and C. L. Heisler.

The following were presented as "Topical Discussions":

"What does it cost to run trains at high speed?" and "Protection of Penstocks from Corrosion." On high-speed trains Mr. W. F. Mattes contributed discussion, and D. J. Lewis on penstocks.

At the close of the papers and discussion Mr. Rockwood rose to call attention to the loss of time which had been entailed upon those members who had familiarized themselves by full reading of the papers of the meeting, in advance of their presentation by the authors. He called attention to the fact that where the subject was really of interest to that person, the methods of the Society which are now practised gave every one a chance to read that paper at his leisure, and that the interest of the conventions lay in the discussion elicited by the paper and not in its *pro forma* reading by its author. When the meeting was a crowded one with respect to papers, and when the heat or other external conditions made the environment unfavorable, it was a fatal injury to the meeting to have the members wearied out by the full reading of papers. He urged, therefore, that the matter should be very carefully considered of a return to former methods, when papers were read by abstract, occupying but five minutes.

The Secretary spoke in reply in earnest and emphatic concurrence of the points made by Mr. Rockwood, and referred to the fact that as a rule the authors themselves were the transgressors and that he would be very glad if the custom could be inaugurated to read the papers exclusively by title, or that every paper should contain at its close full lines of summary, which alone should be read at the meeting and should constitute the presentation of the paper. Mr. Rockwood spoke a few words of kindly appreciation.

The Secretary thereupon, on behalf of a committee which had been constituted informally for the purpose, presented a series of resolutions in which the members might express in

united form their thanks and recognition for the work of the Local Committee in arranging for the events of the meeting. The report of this committee is as follows:

The American Society of Mechanical Engineers, assembled for its closing session in Cincinnati, at the forty-first convention, desires to put on its records some expression of the thanks and recognition which the members feel for all the courtesies which have been extended to them during their stay in the Queen City.

They would request that Mayor Gustav Tafel, of Cincinnati, will accept the sincere thanks of the Mechanical Engineers for his genial greeting and his kindly expressions of welcome at the opening session of the Society. His greeting was but the commencement of that which has been loyally carried forward by the engineers and residents of the city during all the days of the stay of the visitors.

Resolved, That the thanks of the American Society of Mechanical Engineers, assembled in convention at Cincinnati, be extended to the United States Cast Iron Pipe and Foundry Company at Addyston. The visit was an opportunity to study the possibilities of production in a modern plant, and we have greatly appreciated the courtesy of the company and its officers in arranging for our pleasure.

The American Society of Mechanical Engineers desires to express to the Triumph Ice Machine Company its thanks for providing that excursion to the plant of the Cincinnati Oyster and Fish Company. If a jocose reference to the acceptability of refrigerating machinery during a week at Cincinnati at this season may be pardoned, the Society would call this visit a "real triumph."

It is not customary for Mechanical Engineers to confess that any problem which they have to meet is more than enough for them to cope with. If this ever happens, it is when the members of the Society are called on in a formal way to record their thanks and recognition on their own behalf, and on that of the ladies with them, for the unceasing and delightful devotion which the ladies of Cincinnati have shown to the visiting ladies accompanying the members to the convention. Beginning with the opening reception on Tuesday evening, following through the excursions of Wednesday morning, supplemented by their own presence on the excursion of Wednesday, and the charming musical on that evening, and crowned by that most enjoyable visit to the Rookwood Pottery and the Art Museum and the luncheon at the Avondale Club on Thursday, it is only to be said with a sort of bated breath that the men of the party have had to be excluded from that which they would have most thoroughly enjoyed themselves. They are grateful for what they have had, and ask the ladies, on behalf of those who cannot make themselves heard in this meeting, that they will accept this poor attempt to let their feelings in the matter find suitable expression.

It has been manifestly impossible for every member of the Society to avail of every entertainment and privilege which the energy of the Local Committee would have put within their reach during the limited stay of the party in Cincinnati. They would request, therefore, that the Secretary of the Society, in the name of the convention, will draft suitable letters which shall convey to

these hospitable establishments, which have been listed upon our programme, and which we have not all of us been able to visit, the thanks of the members for their kindly disposition to favor our desire and ambition to utilize to the uttermost the occasion of our visit to so important a city in the specialty of machine tools, electrical appliances, and other industrial specialties.

But finally it is to the Local Committee of Arrangements in the Queen City that the members must express their warmest thanks for the labor, for the thought, and for the unwearied devotion to their comfort during their stay, for the delightful success of the Cincinnati meeting. In arranging programme, in securing facilities, in guiding wanderers about the city, there has been no element of kindly effort left untouched to make the Cincinnati convention a memorable one. We would ask that the Local Committee as a whole, and its chairmen of sub-committees individually, will rest assured of heartfelt appreciation on the part of those for whose pleasure their efforts have been expended.

The President then declared the meeting adjourned, the Society to be convened for its annual meeting in the city of New York, unless otherwise directed, during the week following Thanksgiving.

A most enjoyable feature of the Cincinnati meeting was the generous provision made by the Local Committee for the pleasure of their visitors in the matter of excursions to points of interest in the city. Beginning with the afternoon of Tuesday, on which certain members had already reached the city, and extending until the close of the excursion on Friday, this attention was unlimited. It included both members of the Society and the ladies who accompanied them.

On Wednesday afternoon the river steamer "Island Queen" was chartered for an excursion to take the party down the Ohio River, twelve miles, to the plant of the United States Cast Iron Pipe and Foundry Company, at Addyston. The excursion and its music were pleasures in themselves and the visit to the plant an appreciated opportunity.

On Thursday afternoon excursions were made to the plant of the Bullock Manufacturing Company, to the Triumph Ice Machine Company's plant of the Cincinnati Oyster and Fish Company, while individual members made themselves guests of the long list of hosts who had expressed their willingness to have members visit them in an informal and personal way at their places of business.

On Friday the entire visiting party took a special train which had been put at their service for a visit to the plant of the National Cash Register Company at Dayton. The party

was divided into small manageable groups, each in charge of a well-informed guide, for a visit to the departments in detail; and after this was over, an illustrated presentation of the features of the plant—which were unusual from the economic and the productive side—were laid before the visitors in a short lecture. After this again, the guests were entertained at luncheon and with additional opportunity to visit certain other departments, so that the time was filled until the return of the train.

The ladies of the party were received on the opening evening by the Ladies' Committee, and on Thursday they were again entertained by being escorted to the Rookwood Pottery, the Cincinnati Art Museum, and luncheon at the Avondale Club.

The following list includes the list of those establishments in Cincinnati which had invited the members to be their guests at a convenient time during their stay:

American Tool Works Company.
Barker & Chard Machine Tool Company.
Bickford Drill and Tool Company.
I. & E Greenwald Company.
Miller, DuBrul & Peters Mfg. Co.
American Laundry Machinery Company.
J. A. Fay & Egan Company.
Lane & Bodley Company.
John H. McGowan Company.
Blymyer Iron Works Company.
Cincinnati Milling Machine Company.
Cincinnati Machine Tool Company.
Cincinnati Planer Company.
Dreses, Muelier & Company.
Greaves, Klusman & Company.
Fosdick & Holloway Machine Tool Co.
Lodge & Shipley Machine Tool Co.
William Powel Company.
Ralm, Mayer, Carpenter Company.
Schumacher & Boye.
Bradford Machine Tool Company.
G. A. Gray Company.
Globe Wernicke Company.
Straub Machinery Co.
Triumph Electric and Ice Machine Co.
F. M. Watkins Company.
American Fire Engine Company.
Cincinnati Edison Electric Company.
Cincinnati Sharper Company.
The Lunkenheimer Company.
Bullock Electric Manufacturing Co.
Cincinnati Gas Light and Coke Co.
Cincinnati Street Railway.
Cincinnati Water Works.
Houston, Stanwood & Gamble Co.
Laidlaw-Dunn-Gordon Company.
R. K. Le Blonde Machine Tool Co.
Rookwood Pottery.

No. 853.*

PUMPING-ENGINE TEST WITH SUPERHEATED STEAM.

BY E. H. FOSTER, LONDON, ENGLAND.
(Member of the Society.)

HAVING been invited by Messrs. James Simpson and Company, Limited, of London, England, to make a duty test of a small pumping engine which they had recently installed at the city water works in St. Albans, England, the writer believes the results will be found of sufficient interest to warrant the Society's brief attention, particularly with reference to the effect of using superheated steam.

Engine.

The engine was of the Worthington duplex direct-acting type, triple expansion, since there were six steam cylinders arranged in two tandems, three on each side, through which the steam passed successively, and termed "low duty," to distinguish it from the "high duty" or compensated type of engine designed to use steam at considerably higher ratios of expansion. The design of the engine is strictly commercial, more attention being paid to simplicity of construction and fewness of parts than to perhaps unnecessarily shortened ports and reduced clearances. The steam cylinders are jacketed on their sides only, where steam is carried at boiler pressure. The water accumulating in the jackets is ordinarily emitted through a throttled opening adjusted by hand and passes through a coil in the feed tank and open at its extremity. Steam passes from one cylinder to the other through bare cast-iron pipes. The steam inlet and outlet valves are placed underneath the steam cylinders, and the high-pressure cylinders alone are fitted with cut-off valves. The condenser is of the surface type, placed in the main delivery pipe of the pump,

* Presented at the Cincinnati, Ohio, meeting (May, 1900), of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

the water passing on the outside and the steam on the inside of the tubes. The air pumps, also duplex, work horizontally like the main engine, and are driven by rods extending out from the plungers through the water-cylinder heads. The general dimentions of the engine are as follows:

Diameter of high-pressure cylinders	12 inches.
Diameter of intermediate cylinders	18 inches.
Diameter of low-pressure cylinders	20 inches.
Diameter of air-pump plungers	7 inches.
Diameter of main-pump plungers	14 inches.
Nominal stroke of all	18 inches.

Boilers.

The boilers are of the Lancashire two-flue type, six feet in diameter by eighteen feet long, and arranged to be run either by natural draught or an induced draught with a steam jet. Although there are two boilers at the station, only one is necessary to operate the engine.

Superheaters.

The superheaters are placed at the rear of each boiler where the gases leave the flues and turn down to enter the uptake. They are made on the Schwoerer patented system, exposing a single coil of about sixty square feet of external heating surface to each boiler. The steam can be passed all or in part through the superheaters or diverted from them at will. A flexible steam pipe is conveniently arranged to blow off any accumulation of soot on the superheaters, but in practice it is found that they require very little attention.

Service.

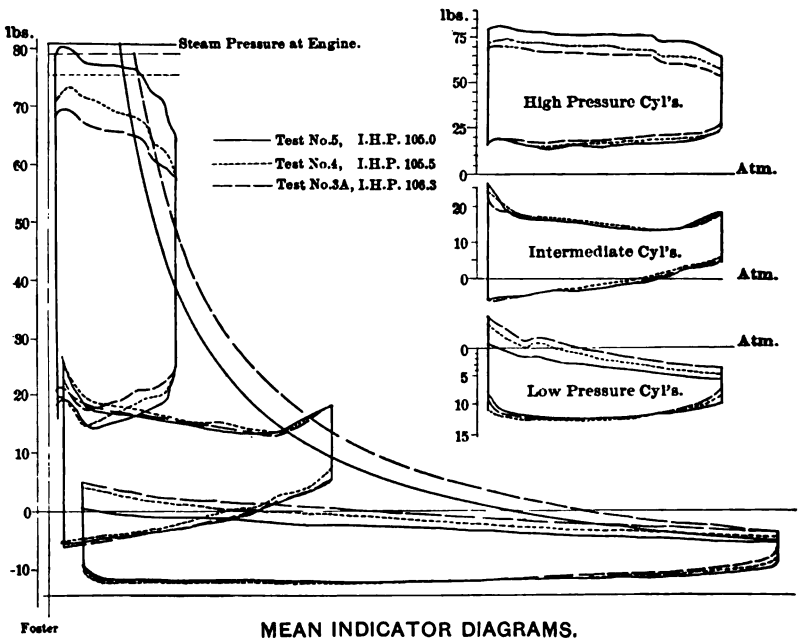
The regular work required of the engine is to fill a reservoir once a day, which requires about five hours pumping at the normal speed every morning. During the rest of the day the fires are allowed to die out and the engine cool off. The water is drawn to the pumps from closed tubular wells. A large chamber on the suction pipe allows the air arriving with the water to free itself and be drawn off through the main air pump.

Arrangements for the Test.

Very complete preparations for the test were made possible through the courtesy of Engineer Phillips of the water company,

and the coöperation of Messrs. Simpson, who supplied an ample staff of experienced observers from their engine works at Pimlico. By opening street hydrants a continuous run of six hours could be obtained, which was deemed sufficient to obtain accurate figures under the existing conditions.

Duplicate gauges were placed on both the delivery pipe and the suction pipe, and the water pressure was noted every five minutes.



MEAN INDICATOR DIAGRAMS.

FIG. 225.

Thermometers were placed in pockets in the steam pipe at the boiler, at the superheater, at the engine throttle, and at the engine exhaust, besides the usual thermometers for the feed-water, jacket-drain, and engine-room temperatures. The thermometers were especially compared at Kew Observatory and the pressure gauges were tested on a mercury column before and after the test of the engine.

Weighing tanks were provided for the air pump discharge, jacket drain, and boiler feed, and amounts carefully checked every hour.

Indicator cards from the steam cylinders were taken every half

hour and averaged with a planimeter on the spot. The indicator springs were also tested for accuracy by the makers and pronounced correct. The engine had been working about five hours daily for three weeks.

Tests.

Five runs of six hours each were made on consecutive days, with the engine doing its regular work, but under different conditions of adjustment, as follows:

No. 1 and No. 4. With superheated steam in cylinders and jackets.

No. 2. Same as above, except with an equalizing pipe, one and one-half inches in diameter, open between the two intermediate exhaust pipes.

No. 3. With saturated steam in engine and jackets, cross exhaust pipe, as above, open half the time, as denoted by 3B.

No. 5. Superheated steam in engine, jackets open to atmosphere.

After the first day's test the weighing of the water fed to boiler was neglected, since it was found that these weights agreed within one-half of one per cent. of the water discharged from the air pump and jackets, and these latter quantities are more easily obtained accurately on a short test.

The pump horse-power is calculated from plunger displacement based on the observed length of stroke, which was noted every five minutes, no allowance being made for slip nor credit given for a head of two feet of water over the air-pump delivery valves.

Discussion of Results.

From the figures obtained we may conclude with reference to engines of this type:

First. Steam when superheated about 125 degrees Fahr. will do sixteen per cent. more work than when saturated.

Second. With steam superheated as above and the feed water passed through an exhaust heater, a given amount of fuel will produce from eleven to twelve per cent. more work.

Third. The effect of steam jacketing all the cylinders is only to produce a saving of about four per cent. of the fuel, or three per cent. of the feed water, under the above conditions of superheated steam and feed water heated by exhaust.

Fourth. That the use of even a small cross-over exhaust pipe between the intermediate and low-pressure steam cylinders, while somewhat beneficial to the running of the engine, causes an increase in steam consumption of about five per cent.

Fifth. With an allowance of two per cent. for losses due to slip and leakage this engine shows that it can easily perform a duty of 96,000,000 or 97,000,000 foot pounds per 1,000,000 British thermal units, or of giving an effective horse-power on 18.3 pounds of superheated steam per hour, which latter corresponds to 108,-200,000 foot pounds duty per 1,000 pounds of steam; certainly a most excellent result for an engine of this class.

TABLE OF RESULTS.

NUMBER OF TEST:	3B.	3A.	2.	5.	1 and 4.
Date, 1899	Nov. 6.	Nov. 6.	Nov. 5.	Nov. 8.	Nov. 4 & 7.
Duration	3 hours.	3 hours.	6 hours.	6 hours.	6 hrs. each.
Average steam pressure at boiler, pounds	88.00	87.54	84.48	89.04	84.50
" " " engine, "	79.3	79.1	76.4	80.9	75.7
Average total head, feet	235.8	238.7	236.5	236.7	240.
Air-pump discharge per hour, pounds	1,966.0	1,895.6	1,654.1	1,779.0	1,608.8
Jacket drain per hour, pounds	205.3	207.1	143.6	.....	135.3
Total from air pump and jackets, pounds	2,171.3	2,102.7	1,797.7	1,779.0	1,744.1
Average length of stroke in feet	1.56	1.55	1.53	1.56	1.53
Average revolutions per minute	34.02	34.06	33.34	33.02	33.66
Average pump horse-power	99.56	99.25	95.02	96.03	97.
Steam used per pump H. P. per hour	21.81	21.18	18.91	18.52	17.97
Mean effective pressure H. P. cylinders	46.11	44.62	52.15	59.77	51.10*
" " I. P. "	19.52	17.34	19.10	17.65	17.20*
" " L. P. "	9.87	11.06	8.92	8.54	10.27*
Indicated horse-power	106.32	106.79	102.08	105.	105.08*
Mechanical efficiency	.9363	.9307	.9307	.9145	.9306*
Temperatures, Degrees Fahrenheit.					
Air-pump overflow	83.9	83.	76.6	79.	80.
Jacket drain	210.5	210.5	210.3	.....	210.2
Water in main suction	54.	54.	54.	54.	54.
Exhaust from low-pressure cylinders	.....	.....	.....	125.	134.
Steam before superheater	326.	326.	322.40	325.46	321.60
Steam after superheater	.....	.....	466.02	479.56	464.78
Steam at engine	319.33	319.15	438.58	447.56	439.10
Degrees superheat at engine	0.0	0.0	118.58	122.47	117.7
Duty.					
Foot pounds duty per B. T. U. consumed	82.06	84.53	89.56	89.12	94.20
Foot pounds duty per B. T. U. assuming heater in exhaust to raise temperature of feed water to 120 degrees	84.63	87.14	92.70	92.79	97.25

* Indicator cards from Test No. 1, not forming a complete set, were not used in working up the results.

No. 854.*

TEST OF THE SNOW PUMPING ENGINE AT THE RIVERSIDE STATION OF THE INDIANAPOLIS WATER COMPANY.

BY W. F. M. GOSS, LAFAYETTE, IND.

(Member of the Society.)

I.—INTRODUCTION.

THE engine tested was designed and constructed by the Snow Steam Pump Works for the Indianapolis Water Company of Indianapolis, Indiana, and has been in service at the company's Riverside pumping station since the beginning of the year 1897. At the time of its purchase and during its construction and installation, Mr. L. K. Davis was consulting engineer for the water company. The building containing the engine, and all foundations, are of his design. The arrangement of pump valve chambers outside of the foundations is understood to have been adopted in response to his suggestion.

The function of the engine is to draw water from a reservoir or "gallery" and to deliver the same to the mains supplying the city. At its higher level water flows freely from the gallery to the suction-valve chambers of the pump, and as the fluctuations in level in the gallery are within the limits of a few feet, the suction lift is never great. Under service conditions the water pumped is delivered at a pressure of 80 pounds per square inch, and for fire service at a pressure of 150 pounds.

Tests of the pump were undertaken under the immediate direction of Mr. F. A. W. Davis, Vice-President of the Indianapolis Water Company, the first test having been run July 5, 1893. The character of this test was similar to that of tests ordinarily employed in determining duty performance, and all usual precautions were taken to avoid errors in the work.

---

* Presented at the Cincinnati, Ohio, meeting (May, 1900), of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

The results, however, disclosed a performance so remarkably high that, while not disposed to question unduly or to discredit the conclusions reached, the writer earnestly recommended that they be looked upon as tentative, until verified by a test conducted upon a broader plan, which would give an array of data sufficiently elaborate to allow a more thorough analysis of the action of the several parts of the machine. In accord with this recommendation, directions were given to proceed with the work of a second test, which was made during the following December, the results of which are herein recorded.

While for obvious reasons the test of December 3d constitutes the subject of the present paper, it now appears that it is not more reliable, so far as duty performance is concerned, than the first test of July 5th. The results of the two tests are in substantial agreement, and those of the earlier test as well as of the later have been widely quoted. For these reasons it has seemed best not to ignore the existence of the earlier test, and hence a statement concerning it, together with an exhibit of data and results derived therefrom, will be found presented as an appendix accompanying this paper.

It is to be noted that the presentation of the present paper falls something more than a year and a half after the tests described were run. Reasons for delay in publication are not in themselves important, but the fact that papers dealing with pumping-engine tests of a later date have been presented to the Society in the interim, places this paper out of its natural order. It is, however, believed that the significance of the results justifies their being given a place in the *Proceedings* of the Society, even though they must be made of record at a date which is later than could be wished.

Acknowledgments should be made to Mr. F. A. W. Davis, of the Indianapolis Water Company, who was untiring in his efforts to promote the work; to Mr. John Rail, who, as engineer of the water company, had immediate charge of the pumping station, and who, by his hearty spirit of coöperation made easy the solution of problems which were really difficult; to Mr. E. C. Sornberger, who in both tests represented the builders of the engine, and assisted in many ways; to Prof. R. S. Miller, of Purdue University, Junior Member of the Society, under whose immediate direction the observers did their work; and, finally, to fourteen senior students of Purdue University, who through-

out the second or formal test acted as observers, and each one of whom was skilled in the work assigned. All maintained their stations without relief throughout the twelve hours of the test.

II.

Description of the Engine.

The engine is designed to pump 20,000,000 gallons in twenty-four hours. It is of the vertical triple-expansion type, having a single-acting plunger pump below and in line with each of the three steam cylinders. The steam cylinders are 29, 52, and 80 inches in diameter, respectively; the pump plungers are 33 inches in diameter, and each has a stroke of 60 inches. Connecting rods from the cross heads of each cylinder couple with cranks set at 120 degrees, the low-pressure crank leading, and upon the crank shaft are two 20-foot flywheels.

All steam cylinders are jacketed on barrels and heads, and steam coils in the intermediate receivers serve as reheaters. The coils in the first receiver present 316 square feet of surface, and those of the second receiver 710 square feet of surface.

The steam distribution is controlled by valves of the Corliss type, which close promptly when released.

A surface condenser, having 1,062 square feet of cooling surface, connects with a by-pass in the main suction pipe.

A single-acting air pump, 12 by 60 inches, and a single-acting boiler-feed pump, 4 by 60 inches, receive motion from the low-pressure cross head, the latter drawing its supply from the hot well and delivering back to the boilers.

The auxiliary apparatus consists of a direct-acting, steam-driven air pump which, in anticipation of a start, is used to exhaust the air from the main condenser and to prime the water spaces of the suction pipe, and a small Westinghouse air pump for use at intervals to keep up the supply of air in the several air chambers on the delivery side of the pumps. Except for these, the main engine is entirely self-contained.

A general view of the steam end of the engine, as it appeared on the erecting floor of its builder, is shown by Fig. 226, and of the pump barrels and their valve chambers, by Fig. 227. Figs. 228 to 231, inclusive, present copies of general drawings which are self-explanatory.

FIG. 226.

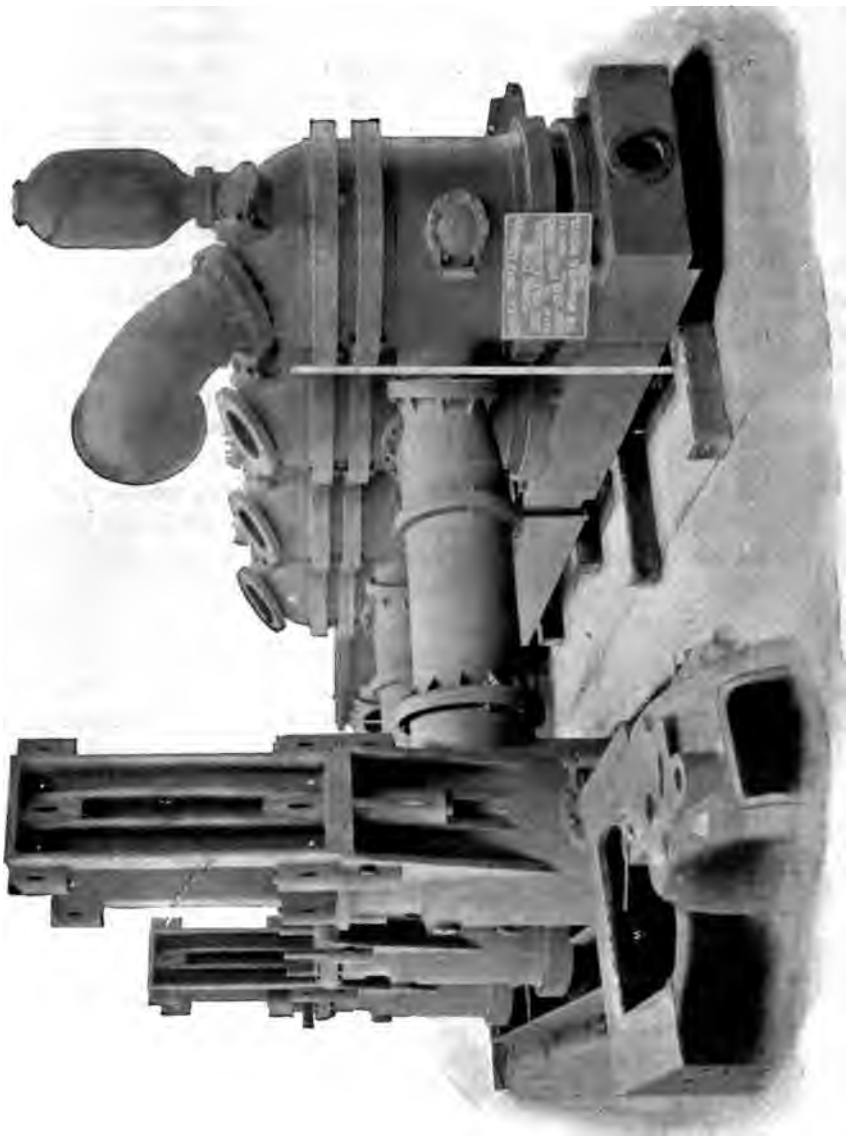


FIG. 237.

It will be seen that the pump chambers are cast separate from the valve chambers, the latter being placed outside of the foundation walls of the engine, an arrangement which permits easy access to the valves and relieves the pump chambers from machinery strains. Each pump chamber is in pipe connection with two valve chambers. This enables the use of large water-valve areas, and at the same time keeps the chambers themselves within limits of a size that makes them safe under the heavy pressure which they must sustain. The two valve decks in each of the six valve chambers are cast as separate parts, and are bolted to place. The valve chambers rest on a continuous bedplate, which also forms the connection through which water is conveyed to them. The three pump chambers, also, are all placed on a massive continuous bedplate which extends the entire length of the engine, and, in addition to the support thus received, are secured to the upper bedplate by large channel-sectioned braces.

It will be seen that this general arrangement makes the machine self-contained and fixes it to its foundation with an unusual degree of security. On either side of the pumps the foundation rises to the main floor level, where it receives the upper bedplates, or the base of the steam end of the machine. This general arrangement, coupled with an unusually massive design, gives a machine which works with great steadiness and which, as the results of the test show, is extremely low in engine friction.

A tabulated statement of all dimensions of the engine which enter into the results of the test or into the value of calculated constants, is presented with the data of the test, Section V.

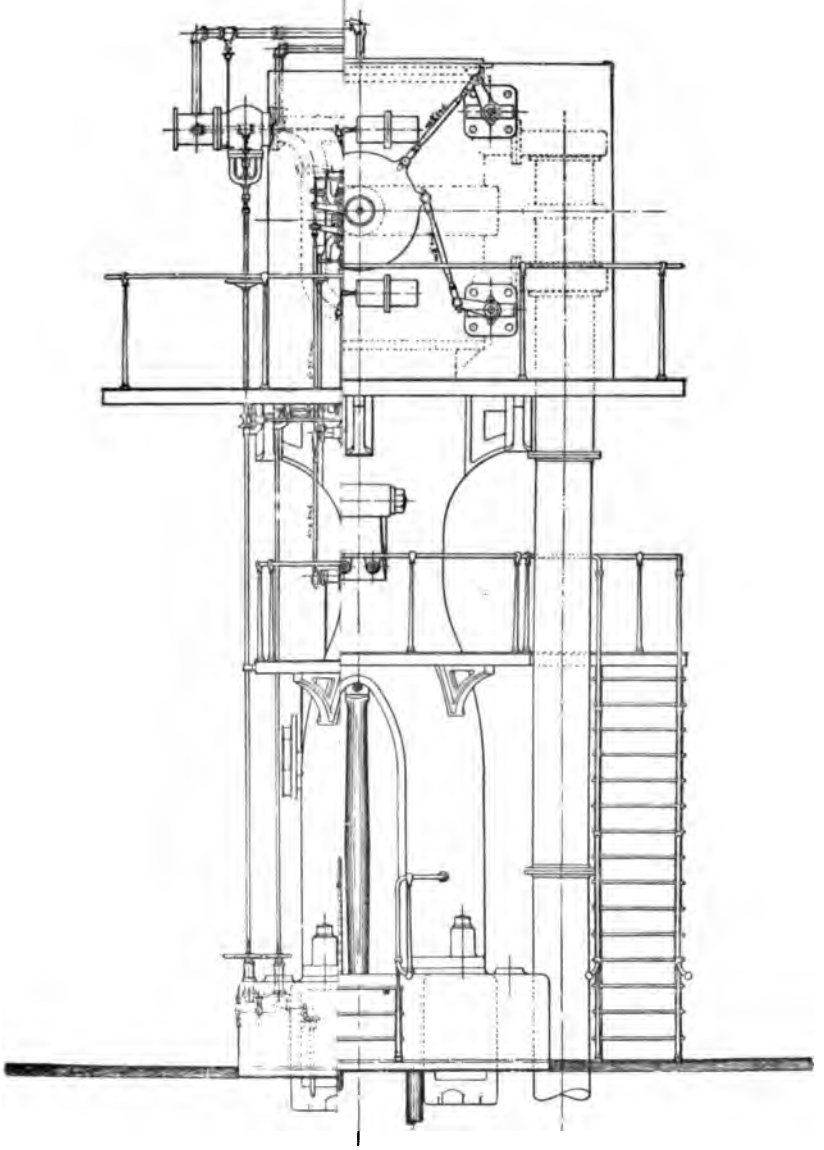
III.

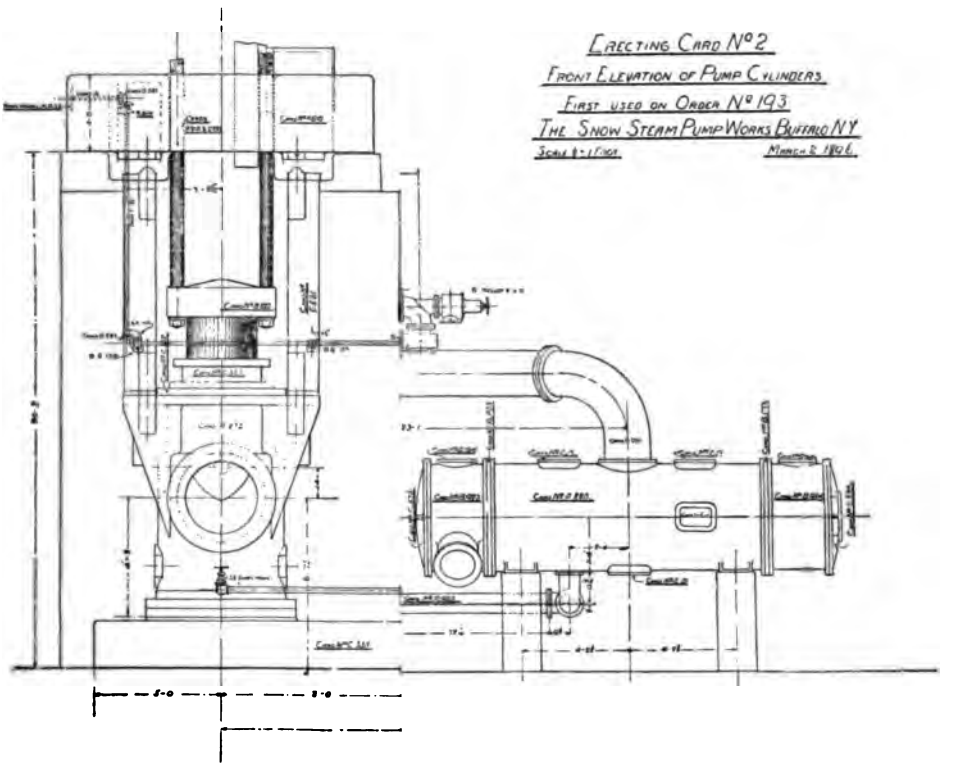
The Formal Test and a Summary of its Results.

The formal test was run on Saturday, December 3, 1898. There had been a trial run during the previous day, in the course of which observers had been perfected in the parts assigned, and, as noted elsewhere, a duty test had been made several months before.*

While a full explanation of the methods employed is reserved

* July 8, 1898. See Appendix for a summary of this test.





540 delivery valves, or a total of more than a thousand valves, a defect in a single one of which would have been disclosed by the tests.

Work of the Steam Cylinders.—The indicated horse-power for

for that portion of the paper presenting a detailed exhibit of data (Section V.), it should be stated in this connection that the amount of steam used by the engine was found by weighing separately the condensation delivered from the condenser, and from the drains of the several jackets and reheaters. Values thus obtained were checked by weighing the feed water delivered to the boiler. Carefully calibrated indicators were used on each end of each steam cylinder, and on each pump. The drum motion of all indicators was well-nigh faultless. Gauges for showing water pressures were attached to air columns on the suction and delivery side of the pumps, and all gauges and indicators were tested under conditions of service both before and after the test. Observers were employed in sufficient number to allow the work of each one to be easily performed in the time assigned, and all maintained their station through the test of twelve hours' duration.

Water Pressure.—The total pressure against which the pumps were operated, as shown by the average of 5-minute observations from gauges connected with the suction and delivery pipes, was 89.2 pounds. The pressure in the force main was 81.5 pounds, and was maintained with great constancy throughout the test, as will be seen from charts (Figs. 232 and 234) taken from a Bristol recording gauge connected with an air column on the pressure side of one of the valve chambers.

Capacity.—During the 12-hour test, the lowest rate of speed for any 5-minute interval was 19.2 revolutions per minute, the highest was 22.2 revolutions, and the average for the whole 12 hours was 21.2 revolutions per minute. This speed gives the pumps a capacity based on plunger displacement of 20.3 million gallons per 24 hours.

Leakage.—In anticipation of the trial, careful tests were made to determine the amount of water leaking past valves and plungers. It was found that such leakages from all sources combined amounted to but a few thousandths of one per cent. of the water pumped, justifying the conclusion that for all purposes, either practical or theoretical, the pumps were tight. This statement involves the plunger packing, 540 suction valves and 540 delivery valves, or a total of more than a thousand valves, a defect in a single one of which would have been disclosed by the tests.

Work of the Steam Cylinders.—The indicated horse-power for

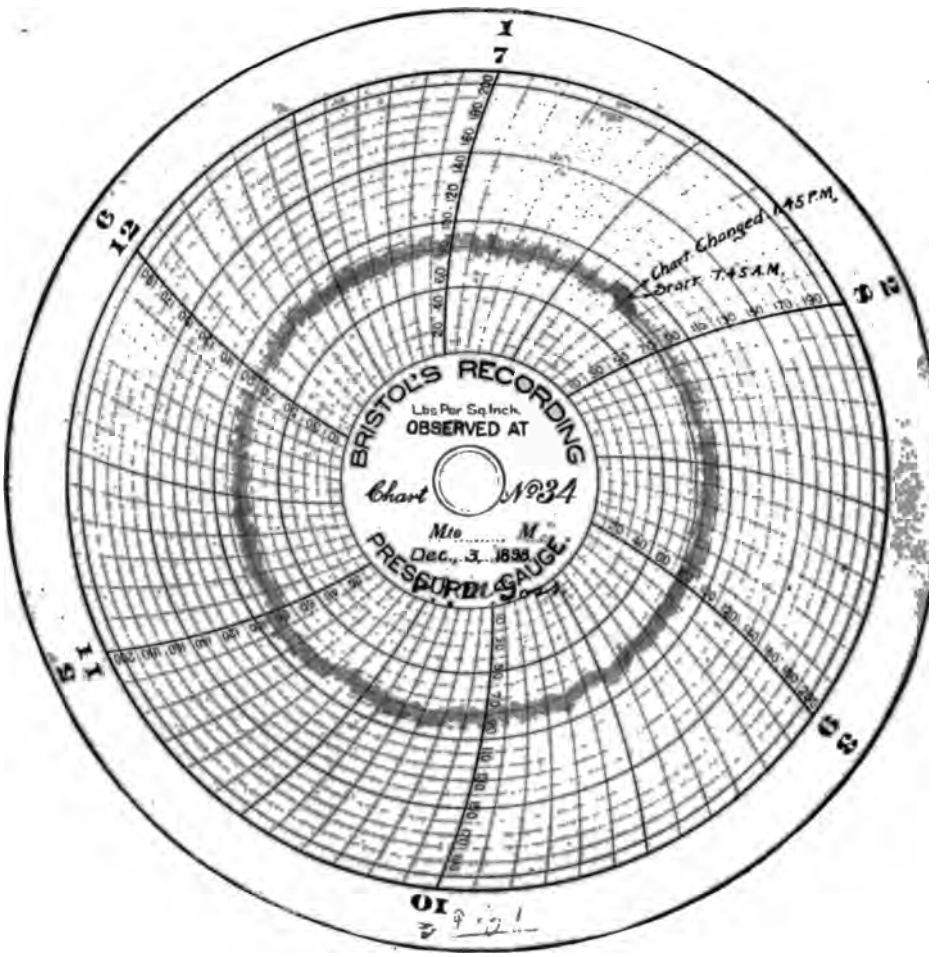
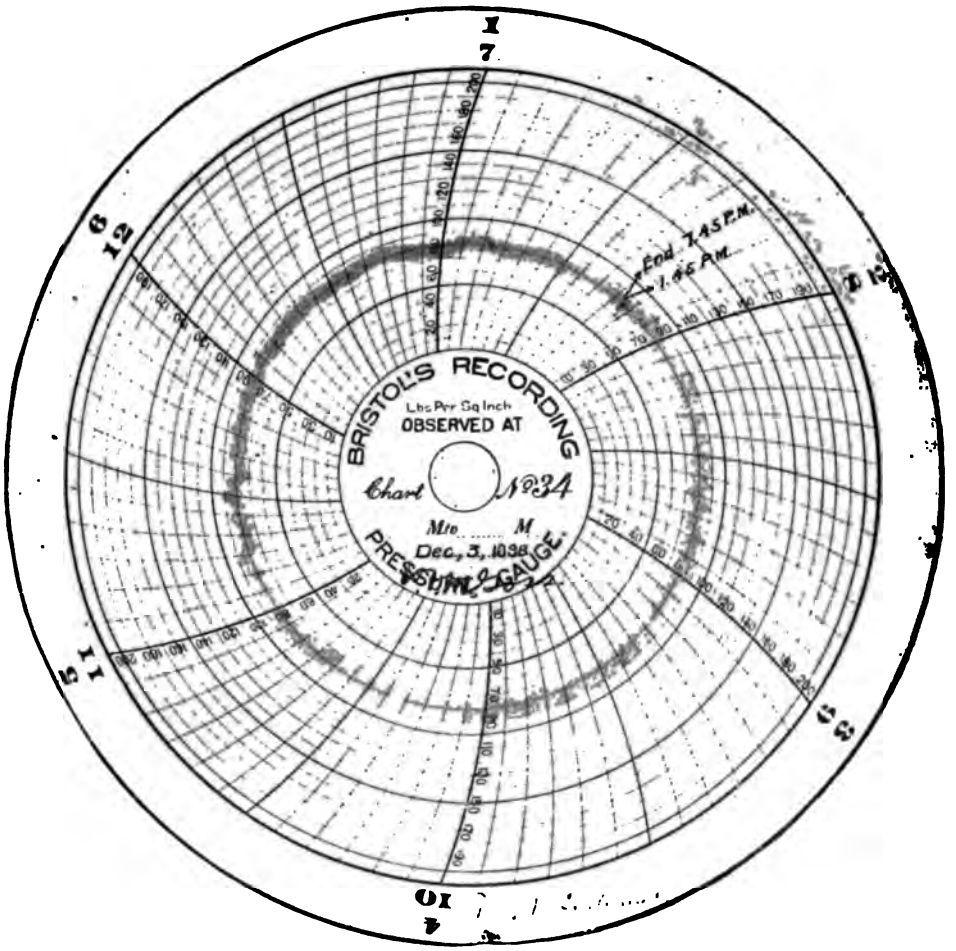

BRISTOL'S RECORDING
Lbs Per Sq Inch.
OBSERVED AT
Chart No 34
Dec. 3 1838
PRESSURE GAUGE
Chart Changed 1.45 P.M.
Start 7.45 A.M.

FIG. 232.


BRISTOL'S RECORDING
Lbs Per Sq Inch
OBSERVED AT
Chart No 34
Dec., 3, 1038
PRESSURE GAUGE
End 7.45 P.M.
1.46 A.M.

51 FIG. 234.

the whole engine under the conditions of the test is 782.9, divided between the several cylinders as follows :

High-pressure	257.6
Intermediate	224.5
Low-pressure	300.8
Total	782.9

Had the load been equally distributed, each cylinder would have developed approximately 261 horse-power. The power of the high-pressure cylinder agrees closely with this value, while that of the intermediate and low-pressure departs somewhat from it, the difference in each case being 36 and 40 horse-power, respectively.

A set of typical steam cards at the same scale as taken is presented at Fig. 233, and a combined card is shown by Fig. 235.

Work of the Water Cylinders.—The horse-power developed in the water cylinders as shown by indicators is 736.3, divided very nearly equally among the three pumps. Cards representing the conditions of the test (21 revolutions per minute) are shown by Fig. 236, and similar cards taken when the speed had been reduced to 15 revolutions per minute are shown by Fig. 237. All were taken with the indicator cock wide open, no attempt being made to smooth out the lines by throttling. The springs also were sufficiently light to lend a ready response to the varying pressure in the indicator cylinder. How much of the vibration recorded upon the card represents changes of pressure in the pump, and how much is due to the inertia of the water in the indicator and its connection cannot be known, but the cards undoubtedly greatly magnify changes of pressure.

Steam Used.—The steam delivered to engine throttle contained one per cent. of moisture. The weight of moist steam used during each hour of the test is shown by Table I. In this table, column 2 gives the weight exhausted from the low-pressure cylinder; columns 3 and 4, the weight from the drip pockets of the first and second receivers, respectively; columns 6, 7, and 8, the weight from the jackets of the high-pressure, intermediate, and low-pressure cylinders, respectively; and column 9, the weight from the reheater coils of the two receivers.

The total weight of moist steam used for the test, for all purposes, was 108,011 pounds, or an average of 9,001 pounds per

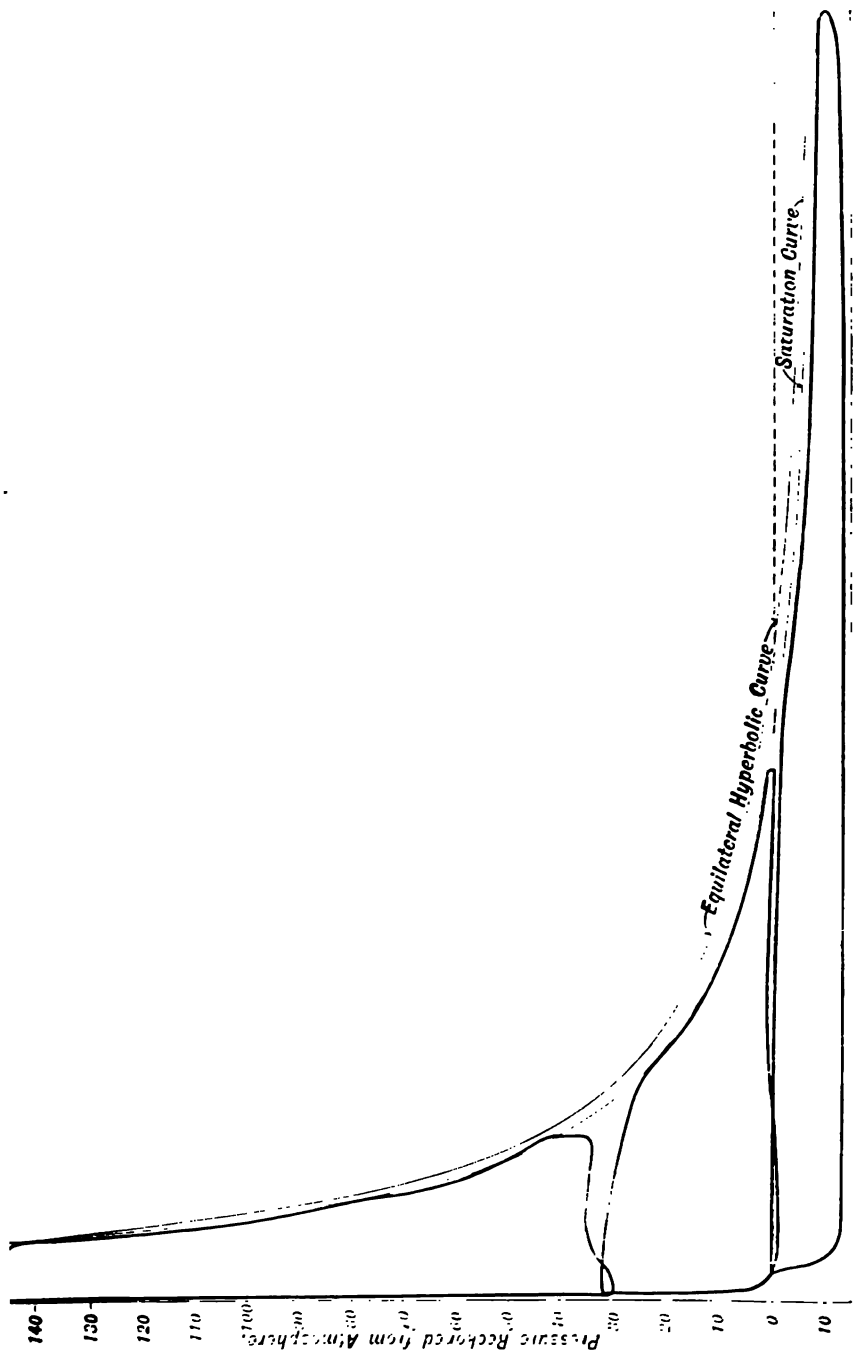

Saturation Curve
Equilateral Hyperbolic Curve
Pressure Reckoned from Atmosphere.
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10

FIG. 235.

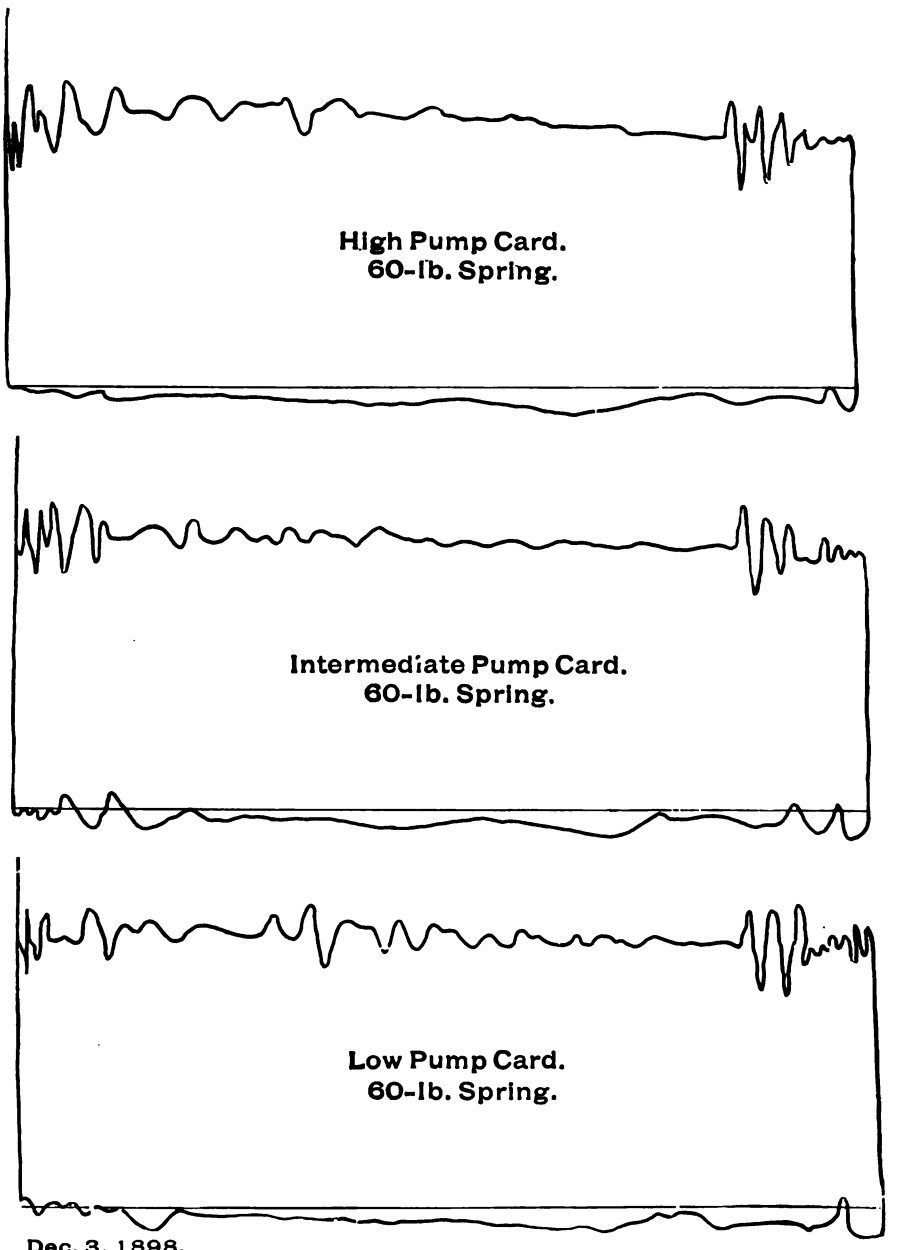

High Pump Card.
60-lb. Spring.
Intermediate Pump Card.
60-lb. Spring.
Low Pump Card.
60-lb. Spring.
Dec. 3, 1898.

FIG. 236.

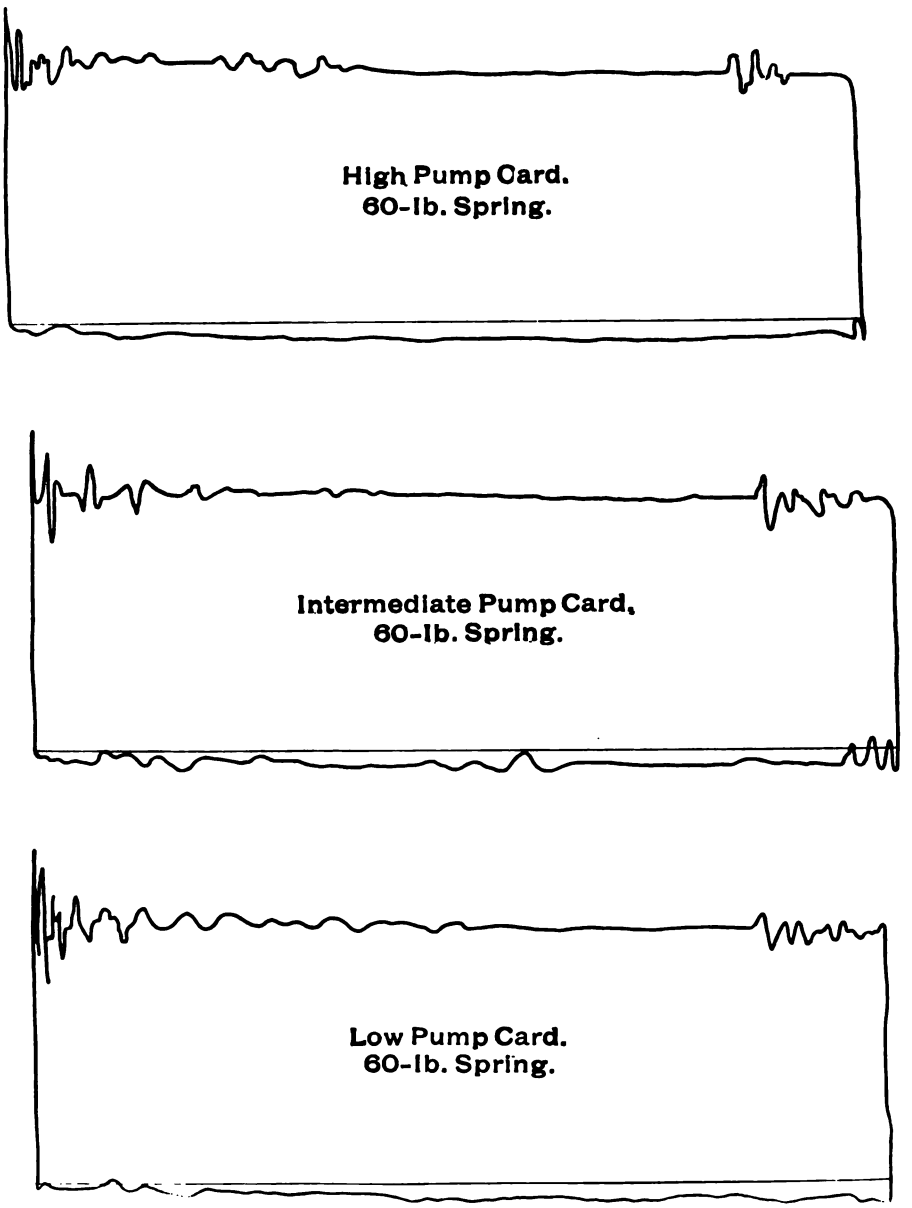

High Pump Card.
60-lb. Spring.
Intermediate Pump Card.
60-lb. Spring.
Low Pump Card.
60-lb. Spring.
Dec. 3, 1898.

FIG. 237.

hour. The actual weights observed per hour, as shown by column 11, disclose a maximum variation from the average rate of a trifle more than 2 per cent., a difference due doubtless to variation in the speed of the engine.

The greatest variation in the hourly rate is to be seen in the product of condensation discharged from the reheater coils. The trap controlling this discharge failed to work satisfactorily, and outflow was finally controlled by a globe valve. Between the engine and the weighing barrel, in the case of this discharge pipe, there were several hundred feet of 2-inch pipe, laid out of doors and made to serve as a cooler. This evidently was not allowed to drain perfectly until near the close of the test, when the valve was opened sufficiently to clear the pipe.

The record by hours, with the exception to which attention has just been called, is one of remarkable uniformity.

Duty Performance.—The test shows the engine to have performed 17,452,000,000 foot-pounds of work at the pumps, on a consumption of 118,346,000 British thermal units, or 147.5 million foot-pounds of work per million British thermal units consumed.

This is not only greater than that which had been reported for any engine up to the time this test was made, but is one which, measured from an absolute basis, is marvellously high. By it the engine is raised to the rank of a record-breaker. The fact that a year later, in the spring of 1899, its high performance was excelled * by an engine presenting novel features in design does not discredit the performance of the Snow engine, but rather enlarges the measure of the tribute due the skill and ingenuity of the American engineer.

Steam and Heat.—The consumption of steam per indicated horse-power per hour is 11.38 pounds. A perfect engine working under the same range of pressures would require 9.2 pounds of steam per horse-power per hour. Again, a consumption of 11.38 pounds of steam per horse-power per hour, under the conditions of pressure and temperature employed, is the equivalent of 209.9 British units per indicated horse-power per minute. While these results had been equalled and slightly exceeded by the performance of the Leavitt engine of Chestnut Hill (Section IV.) they are remarkable as having been obtained from an engine in the design of which no special or unusual effort was made to secure

* See "The Steam Engine at the End of the Nineteenth Century," a paper by Dr. R. H. Thurston, presented at the December meeting, 1899.

TABLE I.

Weight of Condensed Steam, by Hours.

Test of December 3, 1898. W. F. M. Goss.

Hours.	From Cylinder and Receiver. (Pounds.)				From Jackets and Reheater. (Pounds.)					Total Weight Steam Supplied Engine Each Hr. (Pounds.)
	Condenser.	First Receiver Drain.	Second Receiver Drain.	Total through Engine Cyls.	High-Pressure Jacket	Intermediate Jacket.	Low-Pressure Jacket.	Reheater Coils.	Total from Jacket and Reheaters.	
1	2	3	4	5	6	7	8	9	10	11
1	7,846	228	248	8,322	167	148	103	157	575	8,897
2	8,085	228	263	8,576	145	144	111	71	471	9,047
3	8,187	228	263	8,678	163	144	97	140	544	9,222
4	8,025	244	248	8,517	182	147	92	91	512	9,029
5	7,816	244	263	8,323	179	147	104	79	509	8,832
6	8,120	228	248	8,596	205	147	110	100	562	9,158
7	8,036	244	263	8,543	203	142	81	79	505	9,048
8	7,941	228	248	8,417	170	144	85	71	470	8,887
9	8,023	228	251	8,502	169	140	94	92	495	8,997
10	7,787	228	248	8,263	184	143	93	64	484	8,747
11	7,864	244	248	8,356	160	144	101	221	626	8,982
12	7,709	232	248	8,189	259	146	91	480	976	9,165
Total	95,439	2,804	3,039	101,282	2,186	1,736	1,162	1,645	6,729	108,011

minimum cylinder clearance. It would seem, therefore, that the high performance is to be largely attributed to thorough jacketing, and to a valve action which gives a distribution of steam throughout the cylinders that is altogether excellent.

Thermal Action.—During the test the engine received a total of 118,346,000 British thermal units, 94.6 per cent. of which was consumed in the cylinders and 5.4 per cent. in the jackets and reheater coils. The complete exhibit is as follows:

	B. T. U.	Per cent. of total.
Cylinders	111,957,000	94.6
High-pressure jacket	1,879,000	1.6
Intermediate jacket	1,756,000	1.5
Low-pressure jacket	1,170,000	1.0
Reheater coils of the 1st and 2d receivers	1,584,000	1.3
Totals	118,346,000	100.0

As water of condensation was drawn out of the receiver pockets, each cylinder is to be charged with a different weight of mixture of steam and water. The weight per revolution, as shown by corrected tank weighings, is as follows:

High pressure	6.641
Intermediate	6.458
Low pressure	6.258

Weights shown by the indicator per revolution are as follows:

High-pressure cylinder near point of cut-off	5.448
High-pressure cylinder near point of compression	0.125
Intermediate cylinder near middle of expansion	5.797
Intermediate cylinder near point of compression	0.329
Low-pressure cylinder near point of release	5.920
Low-pressure cylinder near point of compression	0.106

These figures show that reëvaporation attends the progress of the moist steam in its course through the engine. The actual weight of steam is greatest in the low-pressure cylinder. Moreover, as water was drained away from the receiver between the cylinders, the percentage of the mixture which is accounted for as steam increases rapidly with the progress of the mixture. Thus, the percentage of the mixture which is shown by the indicator to be steam is as follows:

At point near cut-off, high-pressure cylinder	80.5
At point near middle of expansion curve, intermediate cylinder	85.4
At point near release, low-pressure cylinder	93.0

The effect of the thorough jacketing is not only shown in the

figures given, but in the fulness of the combined cards which are presented as Fig. 235.

Machine Friction.—The work done in the steam cylinders, as shown by indicators, was 782.9 horse-power. The pump indicators show that there were delivered by the pump plungers 734.5 horse-power, a difference of 48.4 horse-power. This represents the amount of power absorbed by the mechanism of the engine. It equals six per cent. of the indicated power of the engine, a lower machine-friction loss than has ever before been reported. This is undoubtedly to be attributed to good design and workmanship, and especially to the massive character of the machine, which serves to give it a high degree of rigidity.

Hydraulic Friction.—The duty performance is based on pressures observed in the suction and force mains at points where these pipes connect with the engine. Duty thus based does not credit the engine with work done in moving the water through the valve chambers and passages connecting them with the pump cylinders. The assumption is that the work done in moving the water through the passages of the pumps is properly charged against the machine as a loss for which the mechanism is responsible.

In the engine tested, the pump plungers delivered 736.3 horse-power, as shown by indicators attached to pumps. The power delivered, as determined from the readings of gauges on either side of the engine, was 734.5 horse-power, a difference of 1.9 horse-power. This represents the work necessary to move the water through the machine. Its pressure equivalent is, approximately, 0.2 of a pound per square inch, and this in turn is equivalent to a head of about six inches.

The Total Friction may be assumed to be the sum of the machine friction and the hydraulic friction, or 50.3 horse-power, or 6.2 per cent. of the indicated horse-power.

IV.

A Comparison of Significant Results with those Obtained from Other American Engines of Exceptional Performance.

The modern high-duty pumping engine has for several decades been constantly undergoing a process of development. At fre-

quent but irregular intervals new engines have appeared, each in its turn approaching more nearly the performance of a perfect engine. Omitting for the sake of brevity reference to several notable machines, it may be said that two of these, the performance of which has received very general attention, are the Allis engine of the city of Milwaukee, tested by Professor Carpenter in 1893, and later made the subject of an elaborate discussion by Dr. Thurston; and the Leavitt engine at the Chestnut Hill pumping station of Boston, which was tested by Professor Miller in 1895. Next in order with these after the Leavitt engine should be placed the Snow engine at Indianapolis, tested in 1898, and constituting the subject of the present paper. At the time it was tested no engine had given so high a performance. A few months after the tests of the Snow engine, however, there came the announcement of a performance of unusual excellence obtained from the Nordberg engine of the Pennsylvania Water Company. A brief comparison of the results derived from these engines appears in Table II.

It will be seen by the table that in duty performance the Snow engine leads by a liberal margin the two earlier engines for which data is presented, while the Nordberg engine, when aided by its system of heaters, gives a performance which exceeds that of all the others, but without its heaters it does not excel either the Snow engine or the Leavitt engine.

The fact that the exceptional result obtained from the Nordberg engine was directly due to the employment of accessory apparatus of a somewhat novel character, should not in any way affect one's estimate of the importance of the results obtained. All possible fields are open to the engineer, and if by the exercise of ingenuity and skill he can reach a result not before attained, it is right for him to do so. But on the other hand, in accepting a result the engineer may properly inquire concerning the means necessary for its attainment, and in this connection it is well to note that in cylinder performance both the Snow and the Leavitt engines do better than the Nordberg, though the latter is a quadruple expansion, and the former are but triple expansion, and that in a comparison based on duty, as obtained by the plain engine unaided by exceptional accessory apparatus, the Snow engine is still to be recorded as having given the highest efficiency yet obtained.

The one element in the performance of the Snow engine which

TABLE II.

1. Name of designer or builder	E. P. Allis Co.	E. D. Leavitt, Jr.	Snow Steam Pump Works	Nordberg Manufacturing Co.
2. Locality	Milwaukee	Chestnut Hill, Mass.	Indianapolis, Ind.	Pittsburg, Pa.
3. Type	Triple expansion	Triple expansion	Triple expansion	Quadruple expansion
4. Extent of jacketing	Barrels and receivers	Barrels, heads and receivers	Barrels, heads and receivers	Barrels and receivers
5. Name of expert conducting test	Prof. R. C. Carpenter	Prof. E. F. Miller	Prof. W. F. M. Goss	Dept. of Experi't'l Eng., Sibley College
6. Capacity million gallons in 24 hours	18	20	20	6
7. Size of steam cylinders, inches	28, 48, 74 x 60	13.7, 24.37, 39 x 72	29, 52, 80 x 60	19.5, 29.0, 49.5, 57.5 x 42
8. Size of water plungers, inches	32 x 60	Double acting 17.5 x 48	33 x 60	14.75 x 42
			Test of July 8, 1898 — Test of Dec. 8, 1898	Test with heaters March, 1899. — Test without heaters March, 1899.
9. Date of test	1893	1895		
10. Total head, lbs	70.40	59.4	88.7 — 89.2	261.5 —
11. Piston speed, feet per minute	203.1	607.0	214.6 — 211.8	255.6 —
12. Pressure near throttle (above atmosphere), lbs	121.4	175.7	155.6 — 154.6	200.0 —
13. Rate of expansion	20.4	21.0	23.8 — 23.4	—
14. Indicated horse-power, I. H. P.	573.9	575.7	— 782.9	712.2 —
15. Friction, per cent	9.2	10.5	— 6.2	6.95 —
16. Dry steam per I. H. P. per hour, including jacket and reheater steam, lbs	11.68	11.22	— 11.38	12.26 — 11.4
17. Per cent. of steam condensed in jackets and reheaters	9.2	17.1	— 6.2	—
18. Dry steam per I. H. P. per hour exclusive of steam used in jackets and reheaters, lbs	10.61	9.8	— 11.67	—
19. B. T. U. per I. H. P. per minute	217.6	204.3	— 209.9	185.96 —
20. Duty based on 1,000,000 heat units, expressed in million foot-pounds	137.7	*144.5	150.1 — 147.5	162.9 — 147.5

* Recalculated from data published by Professor Miller.

permits it to take precedence over previous engines is that of low frictional resistance. While its cylinder action is excellent and must always serve to characterize the engine as one of the finest of its class, the engine could not on the strength of cylinder action alone be shown to be more economical than the Chestnut Hill engine. But aided by small frictional losses the duty performance, in which is summed up the whole action of the machine, reaches well ahead of other previous well-known engines. The significance of this statement is not likely to be appreciated until one considers that the design and construction of high-duty pumping engines have for years been inspired and supervised by men who rank with the best engineers the world has ever seen. The masterpieces of these men have long ago given the pumping engine a place with the finest and most efficient of machines. When, therefore, a new engine appears, which by its exceptional performance places itself ahead of every other machine of its class, no small success has been achieved, for the advent marks an advance of the science of steam engineering, and establishes a new measure for engine performance. It is by such standards as these that the Snow pumping engine in the Riverside station of the Indianapolis Water Company is to be judged.

V.

Data of Test and a Description of Methods by which they were Obtained.

The following table presents a summary of engine dimensions and of the facts derived from the test.

TABLE III.

Engine Constants, Observed and Calculated Data.

Builders' Dimensions.

a. Diameter of cylinder—inches.

High pressure	29.
Intermediate pressure	52.
Low pressure	80.

b. Diameter of piston rods, one side—inches.

High pressure	6.
Intermediate pressure	7.
Low pressure	8.

c. Clearance—per cent. of piston displacement.

High pressure	1.7
Intermediate pressure	2.2
Low pressure	2.5

d. Diameter of pump plungers, three single-acting—inches ..... 33.

e. Stroke of all pistons and plungers—inches ..... 60.

Calculated Dimensions.

f. Effective area of pistons—square inches.

High pressure, head end	661.
High pressure, crank end	632.
Intermediate pressure, head end	2,124.
Intermediate pressure, crank end	2,085.
Low pressure, head end	5,027.
Low pressure, crank end	4,976.

g. Area of each plunger—square inches 855.3

General Data for Test.

1. Duration of test—hours	12.
2. Total revolutions of engine	15,250.
3. Total plunger strokes	45,750.
4. Revolutions per minute	21.18
5. Steam pressure in supply pipe near engine, by gauge—pounds	154.61
6. Barometric pressure—pounds	14.31
7. Temperature of water pumped—° F	55.8
8. Total weight of moist steam used by engine—pounds	108,011.
9. Percentage of moisture in steam	1.0
10. Total weight of dry steam used by engine (108,011 + 0.99)	106,931.

Pump Data—Work Shown by Gauge.

11. Water pressure against which pumps delivered—pounds	81.5
12. Vacuum in suction against which pumps drew—pounds	2.8
13. Pressure equivalent to vertical distance between gauges—pounds	4.9
14. Total pressure against which pumps were operated (81.5 + 2.8 + 4.9)	89.2
15. Foot pounds of work delivered by pumps (855.3 × 89.2 × 5 × 45,750)	17,452,000,000.
16. Total horse-power delivered by pumps $\left(\frac{17,452,000,000}{720 \times 33,000}\right)$	734.5

Pump Data—Work Shown by Indicators.

17.	Mean pressure on pump plungers—pounds.		
	High	89.8	
	Intermediate	88.8	
	Low	89.6	
	Average	———	89.4
18.	Horse-power used by pumps.		
	High	246.5	
	Intermediate	243.8	
	Low	246.0	
	Total	———	736.3

Friction of Water in Passing Pumps.

19.	Pounds pressure necessary to move water through pumps (89.4—89.2)	0.2
20.	Horse-power necessary to move water through pumps (736.3—734.5)	1.8

Cylinder Performance, Observed Gauge Pressures—Pounds.

21.	Supply pipe near engine	154.6
22.	First receiver	32.8
23.	Second receiver	1.7
24.	High-pressure jacket	163.9
25.	Intermediate-pressure jacket	70.7
26.	Low-pressure jacket	15.6
27.	Reheater coils	150.6
28.	Vacuum in condenser	12.7

Cylinder Performance, Observed Temperature—°F.

29.	Discharge from condenser	91.1
30.	Discharge from condenser and receiver drains—hot well	111.9
31.	Discharge from high-pressure jacket	354.3
32.	Discharge from intermediate-pressure jacket	205.0
33.	Discharge from low-pressure jacket	209.3
34.	Discharge from reheater coils	253.2

Cylinder Performance, Observed Weight of Condensed Steam—Pounds.

35.	Discharge from condenser	95,439.
36.	Discharge from first receiver drains	2,804.
37.	Discharge from second receiver drains	3,039.
38.	Discharge from condenser and receiver drains	101,282.
39.	Discharge from high-pressure jacket	2,186.
40.	Discharge from intermediate-pressure jacket	1,736.
41.	Discharge from low-pressure jacket	1,162.
42.	Discharge from reheater coils	1,645.
43.	Weight of moist steam admitted to cylinders per revolution—lbs.	
	High pressure	6.641
	Intermediate pressure	6.458
	Low pressure	6.258

Pump Data—Work Shown by Indicators.

17. Mean pressure on pump plungers—pounds.		
High	89.8	
Intermediate	88.8	
Low	89.6	
Average	———	89.4
18. Horse-power used by pumps.		
High	246.5	
Intermediate	243.8	
Low	246.0	
Total	———	736.3

Friction of Water in Passing Pumps.

19. Pounds pressure necessary to move water through pumps (89.4—89.2)	0.2
20. Horse-power necessary to move water through pumps (736.3—734.5)	1.8

Cylinder Performance, Observed Gauge Pressures—Pounds.

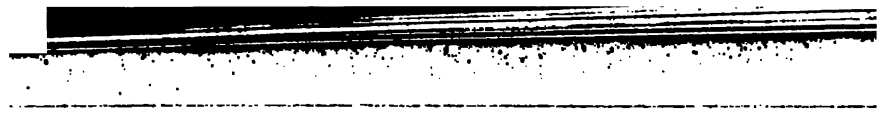
21. Supply pipe near engine	154.6
22. First receiver	32.8
23. Second receiver	1.7
24. High-pressure jacket	163.9
25. Intermediate-pressure jacket	70.7
26. Low-pressure jacket	15.6
27. Reheater coils	150.6
28. Vacuum in condenser	13.7

Cylinder Performance, Observed Temperature—°F.

29. Discharge from condenser	91.1
30. Discharge from condenser and receiver drains—hot well	111.9
31. Discharge from high-pressure jacket	354.3
32. Discharge from intermediate-pressure jacket	205.0
33. Discharge from low-pressure jacket	209.3
34. Discharge from reheater coils	253.2

Cylinder Performance, Observed Weight of Condensed Steam—Pounds.

35. Discharge from condenser	95,439.
36. Discharge from first receiver drains	2,804.
37. Discharge from second receiver drains	3,039.
38. Discharge from condenser and receiver drains	101,282.
39. Discharge from high-pressure jacket	2,186.
40. Discharge from intermediate-pressure jacket	1,736.
41. Discharge from low-pressure jacket	1,162.
42. Discharge from reheater coils	1,645.
43. Weight of moist steam admitted to cylinders per revolution—lbs.	
High pressure	6.641
Intermediate pressure	6.458
Low pressure	6.258



TEST OF S

CARD No.	Low Head.						
	M. E. P.	E. P.	Point near Release.		Point after Compression.		M. E
			Per Cent.	Press. Lbs. Below At.	Per Cent.	Press. Lbs. Below At.	
1	2	22	23	24	25	26	27
2.....	63.2	9.19	97.2	8.5	2.2	12.2	9.
5.....	68.2	9.52	97.3	8.3	2.5	12.0	10
8.....	62.1	9.50	97.0	8.3	2.6	12.0	9
11.....	62.4	9.71	97.2	8.0	2.7	12.0	9
14.....	62.9	9.89	97.0	7.9	2.7	12.0	10
17.....	62.0	9.85	97.0	8.2	2.5	11.8	9
20.....	61.3	9.19	97.6	8.4	2.6	12.2	9
23.....	62.0	9.12	97.2	8.3	3.0	11.8	9
26.....	63.7	9.7	97.2	8.1	3.0	12.0	9
29.....	65.5	9.92	97.3	8.1	2.6	12.0	10
32.....	66.2	0.55	97.0	7.8	4.5	12.3	9
35.....	60.4	8.98	96.8	8.7	2.5	12.1	9
38.....	66.2	0.0	96.8	8.0	2.2	12.0	10
41.....	62.1	8.55	96.6	8.6	3.0	12.4	9
44.....	63.3	8.91	97.0	8.4	2 1	11.9	9
47.....	66.5	8.72	97 0	8.5	2.6	12.3	9
50.....	61.7	8.99	97.2	8.5	2.5	12.0	9
53.....	65.4	8.89	97.1	8.5	3.0	12.2	9
56.....	60.7	9.17	97.3	8.2	2.6	12.2	9
59.....	63.7	8.91	97.2	8.3	2.9	12.1	9
62.....	65.3	8.97	97.0	8.2	2.8	12.1	9
65.....	62.5	9.19	97.0	8.1	3.0	12.0	9
68.....	64.2	9.04	97.1	8.3	2.9	11.9	9
71.....	62.4	8.99	97.1	8.2	2.2	12.0	9
74.....	63.6	9.16	96.8	8.2	2.8	12.0	9
77.....	66.9	8.79	97.3	8.4	3.0	12.0	9
80.....	60.2	8.99	97.1	8.2	2.8	12.0	9
83.....	63.1	8.88	97.1	8.4	2.5	12.0	9
86.....	65.4	9.44	97.1	8.0	3.0	12.0	10
89.....	62.1	8.96	97.0	8.2	3.0	12 0	9
92.....	63.9	9.07	97.1	8.1	3.2	12.0	9
95.....	64.3	9.19	97.4	8.1	3.5	12 2	9
98.....	64.8	9.41	97.1	8.0	3.0	12.2	9
101.....	62.8	9.06	97.0	8.3	3.0	12.2	9
104.....	63.8	9.0	97.0	8.2	4.5	12.2	9
107.....	62.4	8.77	96.2	8.3	3.0	12.1	9
110.....	66.6	9.05	97.1	8.2	3.1	12.2	9
113.....	61.5	9.15	97.1	8.2	3.7	12.2	9
116.....	61.7	8.84	97.3	8.4	2.8	12.2	
119.....	63.5	8.59	97.2	8.6	3.0	12.3	
122.....	64.6	8.85	97.1	8.3	3.0	12.1	
125.....	65.8	9.12	97.3	8.1	3.4	12.1	
128.....	65.3	9.03	97.0	8.1	3.0	12.2	
131.....	67.5	9.01	97.1	8.2	3.1	12.3	
134.....	61.8	8.90	97.3	8.3	2.7	12.1	
137.....	65.2	8.98	97.7	8.3	3.0	12.2	
140.....	62.0	9.02	96.9	8.2	2.8	12.0	
143.....	62.3	9.05	97.2	8.2	3.0	12.1	
Total....	3,055.0	63.6	4,660.2	395.8	139.1	580.3	46
Average.	63.6	9.15	97.09	8.25	2.90	12.09	
Corrected Average							

Indicator Work.

44. Mean effective pressure—pounds.		
High pressure cylinder, head end		63.6
High-pressure cylinder, crank end		60.5
Intermediate-pressure cylinder, head end		16.86
Intermediate-pressure cylinder, crank end		16.38
Low-pressure cylinder, head end		9.15
Low-pressure cylinder, crank end		9.59
45. Indicated horse-power.		
High-pressure cylinder, head end	134.9	
High-pressure cylinder, crank end	122.7	
Intermediate-pressure cylinder, head end	114.9	
Intermediate-pressure cylinder, crank end	109.6	
Low-pressure cylinder, head end	147.7	
Low-pressure cylinder, crank end	153.1	
Total		783.9
46. Weight of steam shown by indicator.		
At point near cut-off, high-pressure cylinder—pounds.		
Head end	2.847	
Crank end	2.601	
Weight per revoultion		5.448
At point near compression, high-pressure cylinder—pounds.		
Head end	0.067	
Crank end	0.058	
Weight per revolution		0.125
At point near middle of expansion curve, intermediate cylinder—pounds.		
Head end	2.973	
Crank end	2.824	
Weight per revolution		5.797
At point near compression, intermediate-pressure cylinder—pounds.		
Head end	0.202	
Crank end	0.127	
Weight per revolution		0.329
At point near release, low-pressure cylinder—pounds.		
Head end	2.845	
Crank end	3.075	
Weight per revolution		5.920
At point near compression, low-pressure cylinder—pounds.		
Head end	0.060	
Crank end	0.046	
Weight per revolution		0.106
47. Quality of steam as shown by indicator.		
At point near cut-off, high-pressure cylinder		80.5
At point near middle of expansion curve, intermediate cylinder.		85.4
At point near release, low-pressure cylinder		93.0

Heat Consumption—B. T. U.

48. Total heat in one pound of steam having a gauge pressure of 154.6 and containing 1 per cent. of water 1,185.3

49. Heat in one pound of water at the temperature of discharge from engine cylinders, 111 9 degrees Fahr..... 79.9

50. Heat in one pound of water at the temperature of discharge from high-pressure jacket, 354.3 degrees Fahr 325.9

51. Heat in one pound of water at the temperature of discharge from intermediate jacket, 205.0 degrees Fahr..... 173.7

52. Heat in one pound of water at the temperature of discharge from low-pressure jacket, 209.3 degrees Fahr..... 178.1

53. Heat in one pound of water at the temperature of discharge from receiver-reheater coils, 253.2 degrees Fahr 222.3

54. Heat consumed in cylinders (1,185.3—79.9) × 101,282..... 111,957,000

55. Heat consumed in high-pressure jacket (1,185.3—325.9) × 2,186 1,879,000

56. Heat consumed in intermediate-pressure jacket (1,185.3—173.7) × 1,736..... 1,756,000

57. Heat consumed in low-pressure jacket (1,185.3—178.1) × 1,162. 1,170,000

58. Heat consumed in receiver-reheater coils (1,185.3—222.3) × 1,645 1,584,000

59. Total heat used by engine during test 118,346,000

Significant Results.

60. B. T. U. per indicated horse-power per minute

$$\left(\frac{118,346,000}{12 \times 60 \times 782.9}\right) \ldots\ldots\ldots 209.9$$

61. Dry steam per indicated horse-power per hour

$$\left(\frac{106,931}{12 \times 782.9}\right) \ldots\ldots\ldots 11.38$$

62. Machine friction in engine and pumps—per cent. of I. H. P.

$$\left(\frac{782.9 - 736.3}{782.9}\right) \ldots\ldots\ldots 6.0$$

63. Hydraulic friction in passage of water through valves and passages—per cent. of I. H. P.

$$\left(\frac{736.3 - 734.5}{782.9}\right) \ldots\ldots\ldots 0.2$$

64. Total machine and hydraulic friction—per cent. of I. H. P. (6.0 + 0.2) 6.2

65. Duty on basis of thousand pounds of dry steam as defined by contract

$$\left(\frac{17,452,000,000}{106,931} \times 1,000\right) \ldots\ldots 163.2 \times 1,000,000$$

66. Duty on basis of a million B. T. U.

$$\left(\frac{17,452,000,000}{118,346,000} \times 1,000,000\right) \ldots\ldots 147.5 \times 1,000,000$$

67. Capacity in gallons per twenty-four hours

$$\frac{45{,}750 \times 855.3 \times 5 \times 12 \times 24}{231 \times 12} \ldots\ldots = 20.8 \times 1{,}000{,}000$$

Observed Data.

A complete abstract of the logs of the test is presented as Table IV., and data derived from indicator cards as Table V.

METHODS AND CONDITIONS.

In explanation of the methods employed in determining the values given in the preceding table (Table III.), the following description is presented. When not otherwise stated references to tables concern Table III.

ENGINE CONSTANTS.

Builders' Dimensions.—The diameters of cylinders, piston rods, and plungers, and the length of stroke, are from the builders' specifications. The clearance data were furnished by the makers' representative, Mr. E. C. Sornberger. No effort has been made to verify the diameters of the cylinders or piston rods, or to determine the clearance. The diameters of the pump plungers, however, were found by passing a thin steel tape around them. Values thus obtained checked closely the builders' figures. The stroke of the plungers and the pistons also was determined experimentally and was found to agree so closely with the values given by the builders that no correction was deemed necessary.

Calculated Dimensions.—The effective area of pistons and plungers was calculated from the builders' dimensions.

DATA FOR TEST.

General Data.—Total plunger strokes (Item 3) is 3 × the total revolutions of engine (Item 2).

The "steam pressure in supply pipe near engine" (Item 5) is the average of readings (column 7, Table IV.), taken at five-minute intervals from a gauge connected to the steam pipe just outside of the engine throttle. The reading of this gauge was checked before and after the test and found to be correct.

The "barometric pressure" (Item 6) is the average pressure at Indianapolis from hourly readings furnished by Mr. C. F. R. Wappanhans of the United States Weather Bureau.

The "temperature of water pumped" (Item 7) during the test is the temperature of the feed water supplied the boiler which was taken from the pump delivery. Readings (column 24, Table IV.) were taken from a thermometer placed in the tub used in weighing the boiler feed water, hence the intervals between them are not of uniform value.

The "total weight of moist steam used by engine" (Item 8) is the sum of Items 38, 39, 40, 41, and 42. (See statement concerning these latter items for methods employed.)

The "percentage of moisture in steam" (Item 9) was determined by a throttling calorimeter applied to the main steam pipe close to the throttle of the engine. The initial steam pressure for the calorimeter is the average given in column 7.

and the pressure in the calorimeter in column 14, Table IV. The temperature of the steam in the calorimeter is that given in column 25, Table IV.

Pump Data.—"Water pressure against which pump delivered" (Item 11) is the average of readings taken from a gauge connected with the air chamber on the delivery side of the pump valves (column 15, Table IV.). The gauge on which the readings were taken was graduated to single pounds and was tested before and after the run and found correct.

As a check on the gauge readings, a Bristol recording gauge was placed in the same pipe connection with the dial gauge already referred to. Its record for the whole test is given as Figs. 232 and 234. It shows the fine degree of constancy which was maintained throughout the test.

The "vacuum in suction against which pumps drew" (Item 12) is the average of readings (column 16, Table IV.) taken at five-minute intervals from a gauge connected with the air chamber on the suction pipe. The readings of the gauge were in inches of mercury and are multiplied by 0.49 to reduce them to pounds per square inch.

The "pressure equivalent to vertical distance between gauges" (Item 13): The gauges being in each case connected to air chambers, show the pressure of the air on the surface of the water in the chambers; hence, the vertical distance desired is that between the water levels in the delivery and suction air chambers. The vertical distance between the bottom of the gauge glasses upon the two chambers was 10.6 feet. The average water level in the delivery air chamber, as shown by readings, was 10.5 inches above the bottom of the gauge glass. The average height of water in the suction air chamber, as shown by readings, was 0.6 inches above the bottom of the gauge glass; hence, the vertical distance, the effect of which is to be added to the gauge readings, is 11.4 feet, corresponding with a water pressure of 4.9 pounds. The arrangement of gauges and water glasses, and the vertical distance between the water levels, are shown by Fig. 238.

Work Shown by Indicators.—"Mean pressure on pump plungers" (Item 17) is the average pressure shown by indicator cards taken at 15-minute intervals. The indicators used were in close pipe connection with the water cylinder, and the drum motion the same as for the steam cylinders. The springs were calibrated cold and the correction expressed in pounds per square inch, found to be for high indicator + 1.9; for intermediate indicator + 1.7; for low indicator + 0.8. (See columns 32 to 34, Table III.)

Data Relating to Cylinder Work.—The "pressure in supply pipe near engine" (Item 21) is the same as Item 5.

The "pressure in first receiver" (Item 22) is the average of readings taken at five-minute intervals from a gauge connected with the receiver near the bottom, and brought down a distance of 13 feet 3 inches to the engine gauge board. The correction for this gauge was found to be: for water column — 5.7 pounds; for error in gauge + 2.5 pounds; total correction — 3.2 pounds (column 8, Table IV.).

The "pressure in second receiver" (Item 23) is the average of readings taken at five-minute intervals from a gauge connected with the receiver near the bottom, and brought down a distance of 13 feet 10 inches to the engine gauge board. The correction for this gauge was found to be: for water column — 6.0 pounds; for error in gauge + 2.5 pounds; total correction — 3.5 pounds (column 9, Table IV.).

The "pressure in high, intermediate, and low-pressure jackets" (Items 24, 25, and 26) is the average of readings taken at five-minute intervals from gauges connected with the jackets about 5 feet above the upper deck. It was found that

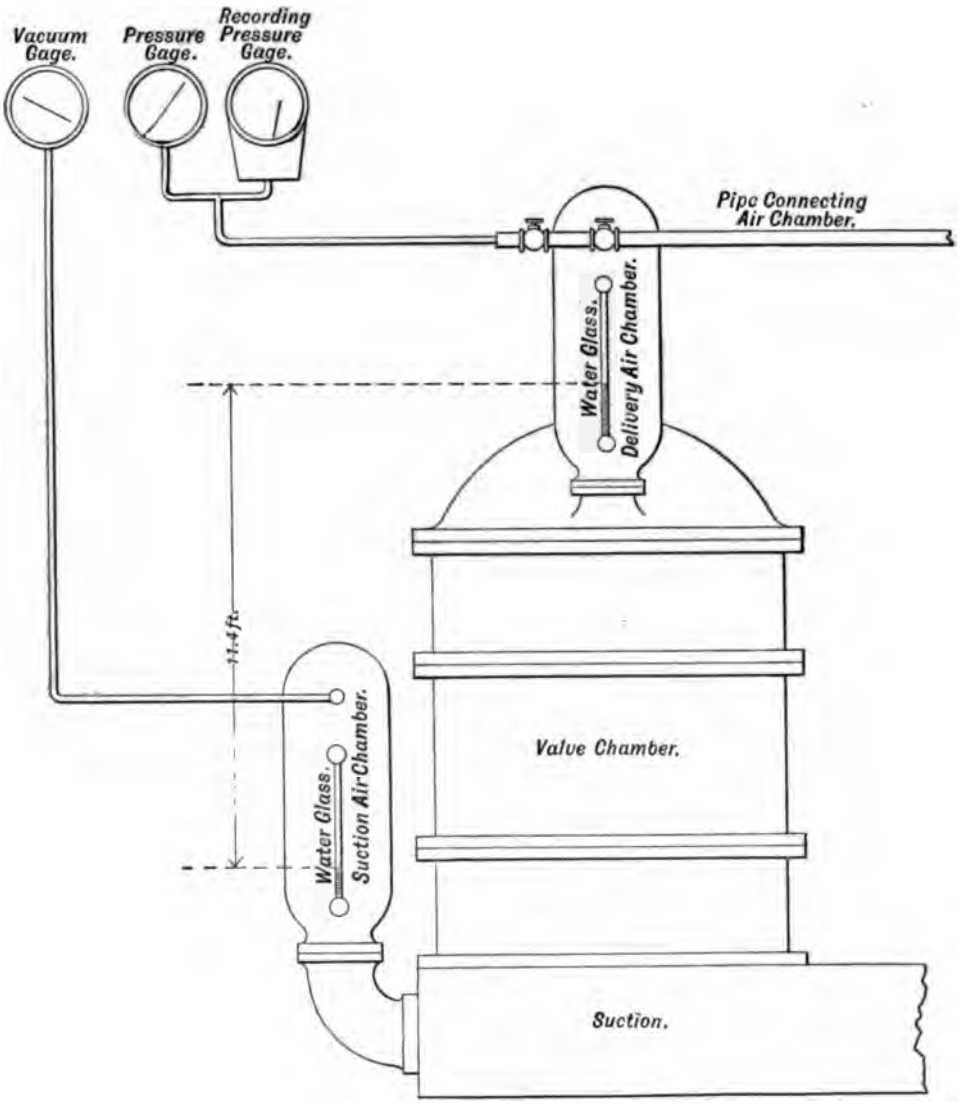

Vacuum Gage.
Pressure Gage.
Recording Pressure Gage.
Pipe Connecting Air Chamber.
Water Glass.
Delivery Air Chamber.
11.4 ft.
Valve Chamber.
Water Glass.
Suction Air Chamber.
Suction.

FIG. 238.

these gauges could not be readily calibrated, and as the pressure in the jacket does not enter into the calculations the readings are presented as taken (columns 10, 11, and 12, Table IV.).

The "pressure in reheater coils" (Item 27) is the average of readings taken at five-minute intervals from a gauge connected with the reheater coils, and brought down 14 feet 3 inches to the engine gauge board. The correction for this gauge was found to be: for water column — 6.2 pounds; for error in gauge, 0.0 pounds; total correction — 6.2 pounds (column 13, Table IV.).

The "temperature of discharge from condenser" (Item 29) is the average of readings taken at five-minute intervals from a thermometer placed in the pipe between condenser and air pump (column 18, Table IV.).

The "temperature of discharge from condenser and receiver drains" (Item 30) is the average of readings taken at five-minute intervals from a thermometer placed in the hot well (column 19, Table IV.). The increase in temperature of the hot well over that of the condenser is due to the discharge of hotter water from the drip pockets of the first and second receivers.

The "temperature of discharge from high, intermediate, and low-pressure jackets and from the two reheater coils" (Items 31, 32, 33, and 34) is that shown by readings taken at five-minute intervals from a thermometer placed in the drain near the steam traps attached thereto (columns 20 to 23, Table IV.).

The "observed weight of condensed steam" (Items 35 to 42). Under normal conditions all water from the engine is led to the hot well and thence to a feed pump attached to the plunger of the low-pressure engine and forced back to the boilers. For the purpose of the test, the feed pump was disconnected and its supply blanked so that no water could pass it, the boiler feed during the test being taken from the force mains.

The water entering the hot well ordinarily comes from the following sources: From the exhaust of the low-pressure cylinder; from drip pockets of the intermediate receivers; from the jackets of the high, intermediate, and low-pressure cylinders; and from the reheater coils of the intermediate receivers It was the plan of the test to determine the amount of water coming from each of these sources. To this end the drains from the several jackets and the reheater coils were taken from the hot well and weighed separately.

The arrangement of piping employed in obtaining the steam record may be briefly described as follows: Under normal conditions the drains of the jacket of the high-pressure cylinder and of the coils of the two intermediate receivers are brought together into a single pipe leading to a trap on the upper deck of the engine. The drains of the jacket of the intermediate cylinder and of the low-pressure cylinder each lead to a separate trap. The several traps deliver to a common discharge pipe, which conveys the drip to the hot well.

For the purpose of the test, these normal arrangements were somewhat modified. The drain from the high-pressure jacket was disconnected from those of the coils, and was led to a new trap. This gave four traps on the upper deck, connected as follows:

1. With drain from high-pressure jacket.
2. With drain from reheating coils in first and second receivers.
3. With drain from intermediate jacket.
4. With drain from low-pressure jacket.

A separate line of temporary piping was run from each trap along the upper deck to a point near the main exhaust pipe, thence down to a level below the main floor, thence out of doors, where it discharged to a line of two-inch pipe

arranged in the form of a return loop to serve as a cooler. The discharge end of the cooler was piped back to the building, ending in a barrel on scales located on the foundation floor.

This complete system of piping, cooling coils, and weighing barrels was duplicated for each trap. In all cases the pipe drained perfectly from trap to weighing barrel. The length of piping in the several cooling coils varied from 125 to 300 feet, and as the weather was cold, the water came to the weighing barrels, with each discharge of trap, sufficiently cooled to prevent any loss by steaming. An exception must be made, however, in the case of that from the coils in the reheaters. As noted elsewhere, the trap which was supposed to control the drip from these refused to work ; the delivery was largely controlled by a globe valve near the trap, the discharge, however, being through the trap. The water from this line was at times hot, and while some losses by steaming occurred, the evidence is that much more steam was allowed to pass the trap than would have occurred had the latter worked satisfactorily.

During the test, also, the main exhaust pipe only led to the condenser, so that the air pump delivered to the hot well the exhaust from the low-pressure cylinder only. There also drained to the hot well the water collecting in the drip pockets of the receivers. The discharge from these, however, was gauged by an observer, who, when they had filled to a given mark on the water glass, drew them down to a definite lower level. From the known capacity of the pockets, the amount of drip from the receivers was calculated, which, when subtracted from the water delivered from the hot well, gave a separate record for the exhaust from the low-pressure cylinder.

The discharge from the hot well was received by a barrel having two 3-inch valves, each over a barrel on scales. The capacity of the barrels, all of which were fitted with 3-inch valves, was well within the requirements, the delivery being at the rate of about one barrel for each 4-minute interval.

In all the arrangement of piping carrying condensed steam, care was taken to avoid errors due to the presence of branch or other connections. All such connections were broken, and, when necessary, blank gaskets were applied. In no case was reliance placed on a valve.

The water record for all sources was brought to a balance at the end of each hour. A review of the hourly results which have already been presented (Table I.) disclosed a record of great uniformity, the slight variations to be seen being chiefly due to variation in speed of engine.

It is to be noted that provisions thus far described for determining the weight of steam deal with water of condensation as delivered by the engine. These arrangements were designed complete in themselves, and results obtained by their aid are now accepted as constituting a satisfactory record. As a check upon them, however, it was determined, in anticipation of the tests, to make weighings of feed water delivered to the boiler, and in the working out of the plan this was done. Because of minute leaks in a long line of large-sized pipe, these were not exact duplicates of those obtained from the engine, but the results disclose a check which is to be regarded as entirely satisfactory.

The "weight of moist steam admitted to cylinders per revolution" (Item 43). The weight of moist steam admitted to the high-pressure cylinder during the test is given by Item 38. Subtracting from this the discharge from the first receiver drain (Item 36) gives the weight admitted to the intermediate-pressure cylinder, and a further subtraction of the discharge from the second receiver drain gives the weight admitted to the low-pressure cylinder. The several weights thus ob.

tained, divided by the total revolutions during the test, give the weight of moist steam admitted to each cylinder per revolution.

Indicator Work.—Cards were taken at 15-minute intervals from six indicators which were in close pipe connection with the cylinders, and had their drums actuated by wires connected to the motion.

The "mean effective pressure" (Item 44) is the average value as derived from cards taken at 15-minute intervals (columns 2, 7, 12, 17, 22, and 27, Table V.).

The "weights of steam shown by indicator" (Item 46) were calculated from data given in Table V., and by the use of Peabody's steam tables.

The "quality of steam as shown by indicator" (Item 47) is found from the data given in Items 43 and 46. The points chosen show the quality of steam soon after admission to the cylinders, when it has gone about half way through the cylinders, and just before it leaves the cylinders.

Heat Consumption.—The twelve items, 48 to 59, were calculated by usual methods from data already given and by use of Peabody's steam tables.

APPENDIX.

Test of July 8th.

At the time this test was run it was not regarded as preliminary to a more formal trial. Later, when the extraordinarily high performance was disclosed by the results, it was thought wise to repeat the work, and to so enlarge its plan as to insure a degree of accuracy not before deemed necessary. The results of the later and more formal test have already been presented. It now remains to review briefly those of the earlier test.

Viewed as a piece of experimental work, the test of July 8th was a most satisfactory one. Desired conditions of running were well maintained, observers were employed in such number as to allow the work of each one to be easily performed in the time assigned, all observers were skilled engineers, and they were especially drilled in the parts they had to perform.

In general, the methods employed were similar to those already described in connection with the formal test, exceptions being found in the following particulars:

1. The duration of the test was less.

2. The steam record was obtained by allowing the condensation from all portions of the engine to drain to the hot well, from which weighings were made as the water issued in a single stream. No attempt was made to check the record obtained at the engine by weighings of feed delivered to the boilers.

3. The indicator drums were driven by a length of cord which was longer than is consistent with most accurate results, and for

this reason data depending upon the indicators are not included in that given below.

The fact should be emphasized, however, that with these exceptions, representing phases of the work which were regarded as outside of the original plan, there would have been nothing in the manner of running the test which could have sustained an objection to the results had they been less significant. A summary of observed and calculated data is as follows:*

Builders' Dimensions.

Diameter of Cylinders—Inches.

High pressure	29.
Intermediate	52.
Low pressure	80.

Diameter of Piston Rods, One Side—Inches.

High pressure	6.
Intermediate	7.
Low pressure	8.
Diameter of pump plungers—inches (three single-acting)	33.
Stroke of all pistons and plungers—inches	60.

General Data.

1.	Duration of test—hours	8.
2.	Total revolutions of engine	10,308.
3.	Revolutions per minute	21.46
4.	Steam pressure in supply pipe near engine—by gauge	155.6
5.	Barometric pressure—pounds	14.3
6.	Temperature of water pumped—degrees Fahr	56.5
7.	Temperature of discharge from condenser—degrees Fahr	79.5
8.	Temperature of discharge from hot well, assumed to be the temperature of feed—degrees Fahr	111.7
9.	Observed weight of water that passed the weighing barrels—pounds	68,648.
10.	Weight of water discharged from hot well, assuming 3 per cent. to have been vaporized before reaching weighing barrels.	70,771.
11.	Weight of water that leaked through condenser during test. To be subtracted—pounds	60.
12.	Total weight of moist steam used by engine—pounds	70,711.
13.	Percentage of moisture in steam	1.2
14.	Total weight of dry steam used by engine—pounds	69,862.

* A complete exhibit of data for this test in connection with that of the formal test has been published by the Snow Steam Pump Works of Buffalo, New York. ("Report of Tests made by Professor W. F. M. Goss, on a Vertical Triple-expansion Crank and Flywheel Pumping Engine having a Daily Capacity of 20,000,000 United States Gallons.")

Pump Data.

15.	Area of each pump plunger—square inches	855.3
16.	Length of stroke of each plunger—feet	5.
17.	Total number of single strokes	30,909.
18.	Water pressure against which pumps delivered—pounds	80.0
19.	Vacuum in suction against which pumps drew—pounds	3.7
20.	Pressure equivalent to vertical distance between gauges—pounds	5.0
21.	Total pressure against which pumps were operated—pounds	88.7
22.	Total horse-power delivered by pumps	740.0
23.	Cubic feet of water which was shown by leakage test to have leaked from plunger and valves during the test	31.4

Heat Consumption.

28.	Total heat in one pound of steam, having a gauge pressure of 155.6 lbs. and containing 1.2 per cent. of water—B. T. U.	1,184.1
29.	Heat in one pound of water at the temperature of hot well, 111.7 degrees Fahr.—B. T. U.	79.7
30.	Heat taken from each pound of steam—B. T. U	1,104.4
31.	Heat consumed by engine—B. T. U.	78,093,000

Results.

I.	Duty on basis of thousand pounds of dry steam used, as defined by contract	167.8 × 1,000,000
II.	Duty on basis of a million B. T. U.	150.1 × 1,000,000
III.	Leakage	Negligible
IV.	Capacity during test in gallons per 24 hours	20.6 × 1,000,000

DISCUSSION.

Mr. Chas. L. Heisler.—Since several papers report tests made on large and medium-sized pumping engines, the following brief description of a newly developed compensating pump may be of general interest, particularly, however, because it is well adapted either to very small or large engines. The small marine pump, Fig. 243, is capable of supplying a 1,000 horse-power battery of boilers. It is triple expansion, having only three steam cylinders, 7, 10, and 14 × 10 inches; the 10 × 10 intermediate cylinder being cast within the receiver shown above the low-pressure cylinder. Plain slide valves are used on small engines. The compensating and valve mechanism does not require more floor space than necessary for the cylinders; the two water ends being 4 × 10 inches. The engine compensates readily for all speeds from 2 to 175 revolutions per minute.

The Compensating Mechanism.

In the four diagrams outlining the steam and pump cylinders, with the intervening compensating link connecting the right and left-hand piston rods, are shown four periods in the cycle or revolution of the pumping engine.

The pump cylinders are of usual construction, and may be of any type suitable for the service. In Fig. 239 the direction of the piston motions is shown by the darts. On the left side the low and intermediate pistons have just completed their upward stroke and are starting on the downward stroke. The right-hand piston is going upward, having nearly completed the first half of the upward stroke, and is just beginning to receive the necessary aid through the compensating link from the left side, which, being at the beginning of its stroke, has an excess of piston pressure; consequently, to avoid undue acceleration, it needs retarding by approximately the amount of the aid extended to the right side, which, without such aid, would hesitate and stop before the completion of the upward stroke. In Fig. 240 the right side has completed the upward stroke and is returning to repay the aid borrowed from the left side, which is nearing the end of its downward stroke. In Fig. 241 the right side is again about to receive aid, and in Fig. 242 is preparing to help the left side, which completes the cycle of operation. In Fig. 244 are printed typical indicator diagrams and in Fig. 243 is a perspective view of the entire machine.

It will be seen that, because of the angularity of the compensating link, the right-side or high-pressure piston is aided through nearly two-thirds of its stroke, upward or downward, and it only extends help to the low-pressure side for about one-third of the latter's stroke. Because of this peculiar and valuable feature steam can be cut off early in the stroke of the high-pressure cylinder. By careful design a very uniform piston motion can be secured when having but one cylinder on the right side and two on the left side, as shown in the diagrams. Moreover, it is manifest that since the low-pressure cylinders cut off steam later than the high-pressure cylinder they need aid only when nearing the end of their strokes. Their excess of power is very readily transmitted through the compensating link to the high-pressure side. Further study will reveal that the compensating link is always in tension when arranged as shown in the diagram. The compen-

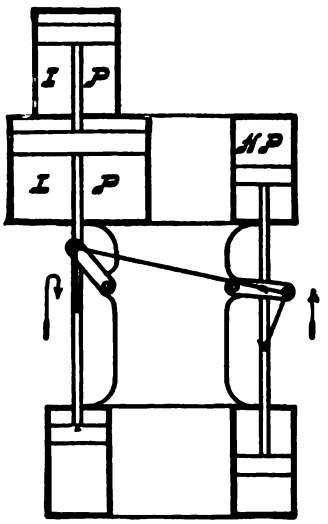


FIG. 239.

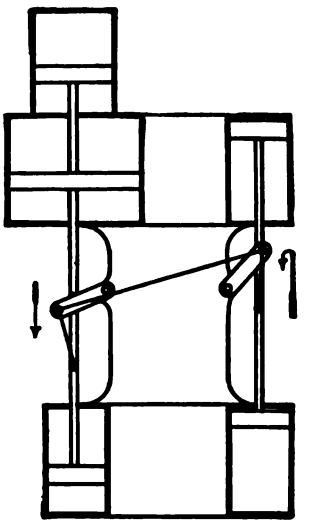


FIG. 240.

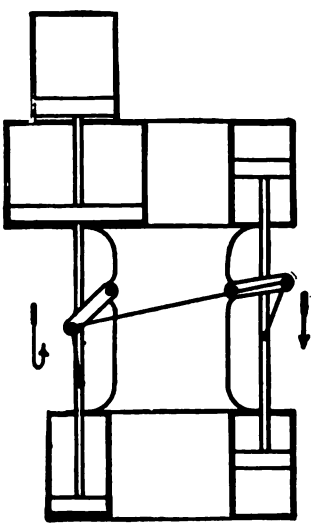


FIG. 241.

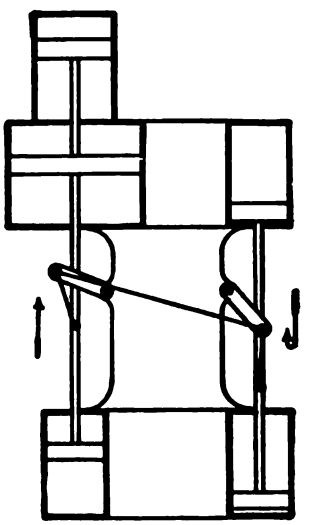


FIG. 242.

TRIPLE-EXPANSION PUMPING ENGINE.

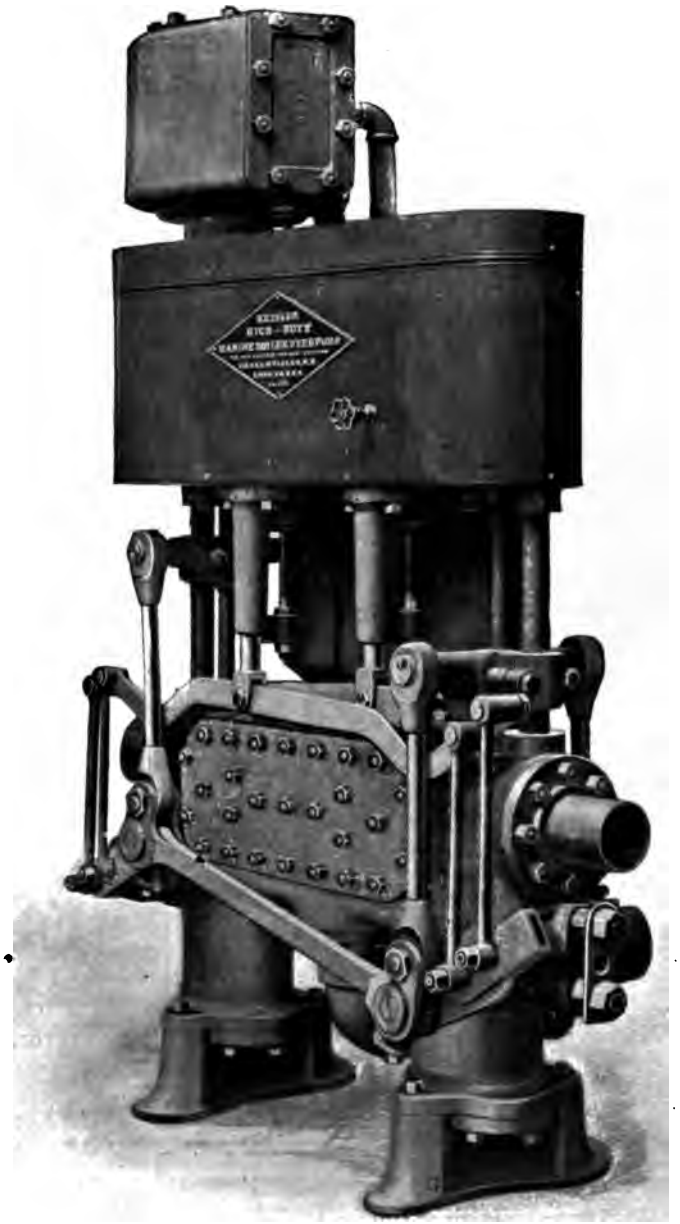


FIG. 243.

sating mechanism has no dead centres, so that the engine can be started in any position. In this respect its action is like that of a pair of engines when "quarter" connected. Evidently the strokes are positive and fixed in length, so that a minimum clearance is made possible. The strokes are related to each other as

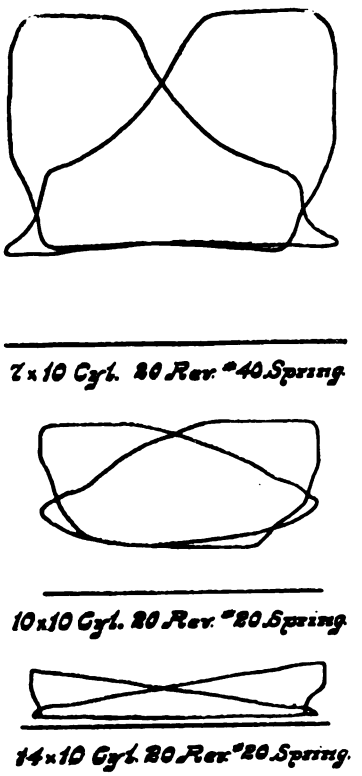


FIG. 244.

in any ordinary duplex pump. The length of stroke, however, is fixed, and gives a minimum clearance.

The Valve Mechanism.

The valve mechanism is equally effective and simple as the compensating device. It gives the much-desired quick opening and closing valve action with an intervening pause. It can be readily adjusted for leads and cut-offs as any ordinary gear; but because of the quick action at the proper instant, accurate equalization of

cut-off can be secured without any unnecessary refinement in adjustment, and which is not seriously affected by excessive wear of the exceedingly simple linkage shown by the cut. When desired, the valve gear can be made adjustable for cut-offs, or controlled by a governor. Each side controls its own point of cut-off, but the time of admission is affected by the piston movement of the other side or engine, like in an ordinary duplex pump.

To appreciate the nature of the service and the results obtained from this small engine when developing only 9 indicated horse-power at 48 revolutions per minute, it may be well to first peruse the following abstract from a paper read at the sixth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 10 and 11, 1898:

"During the past few years considerable attention has been given to the subject of steam economy of the auxiliary machinery on steam vessels, particularly those on warships, where a saving of coal has much to do with the steaming radius of the vessels. Under favorable conditions, as, for instance, in the full-power trials of the United States warships, it has been found that in the case of the main feed pumps the average indicated horse-power developed by such pumps is about one-half of one per cent. of the indicated horse-power of the main engines. I mention this fact to show that feed pumps use more power than any other pumps of a vessel. It will therefore be seen that the feed pump is quite an important auxiliary, and everything should be done to improve its economy in the use of steam. For this reason I have given considerable attention to the subject, and take pleasure in now bringing to the notice of the Society the 'economy test of a unique form of feed pump' recently conducted in England, in which the economy was quite remarkable compared with that of the ordinary type of steam pumps usually employed for feeding boilers.

"Now, it has been shown by tests made, not only by Mr. White, but many others, that the steam consumption of a feed pump of the duplex type (the one most commonly in use in the vessels in the United States Navy) will average about 120 pounds weight of steam per indicated horse-power per hour. In the tests made on the 'Minneapolis' the very best economy shown in the case of the main feed pumps was a little over 93 pounds, while the poorest showing (*i.e.*, when one of the main feed pumps was supplying the donkey boiler, and consequently running at an abnor-

mally low rate of speed) was over 200 pounds per indicated horse-power per hour. The particular pump my paper refers to did its work with an expenditure of only 52 pounds of steam per indicated horse-power per hour, which, considering the fact that it was quite a small unit, is a most excellent showing. In other words, this special form of pump uses considerably less than one-half the steam required ordinarily by a duplex pump of the simple type."

The small compensating engine, when operating under the same conditions, 110 pounds steam pressure, running non-condensing, readily develops an indicated horse-power from only 26 pounds of steam per hour, which is but half of the steam required by the engine referred to in the abstract. Of course larger engines give proportionately better results. The simple construction of the engine permits it to be cared for by engine runners of ordinary intelligence; therefore it will find a large field in medium-sized water works, factories, and paper mills. Moreover, because of the fixed stroke giving a minimum clearance, insuring high steam economy, the larger fly-wheel engines may find in it a strong competitor. From a report in a recent trial of one of these pumps at the Edison Electric Light Station at Erie, Pa., made on May 4th, by Messrs. Gillespie and Gingrich the following extracts are taken:

"The pump has a good action whether running at 3 or 175 revolutions per minute. Of course the latter speed is unusual, and is only reached in case of accident. However, as the stroke is fixed, there is no more danger of the pistons striking the cylinder heads than in an ordinary engine. The clearances are a minimum, and this small engine does not exceed 5 per cent. of the cylinder volume.

"No special preparation was made for the test, which was made only to corroborate previous runs. All the exhaust steam was condensed, and measured by a vessel holding just 23 pounds of the condensed steam. One-half pound extra was charged to the engine with each measure to make ample allowance for any possible leakage.

"Steam pressure at the pump was 110 pounds gauge. The engine ran non-condensing. Average speed, 48 revolutions per minute. The amount of steam used was 10 measures per hour, making a total of 230 pounds, to which add 5 pounds for possible losses, making 235 pounds. The horse-power developed in the high-

pressure was 3.57; in the intermediate, 2.91; and in the low, 2.69; resulting in a total of 9.17 indicated horse-power. This divided into 235, gives 25.6 pounds of steam per indicated horse-power per hour.

"An examination of the indicator cards will show that such results may be reasonably expected from even so small an engine, which certainly are very remarkable when compared with what has been obtained from boiler-feed pumps in the past."

Prof. F. L. Emory.—I want to ask one question only regarding the combined cards in these two papers by Messrs. Cooley and Goss, and that is whether the combined cards were drawn by following one charge of steam through the cylinders, or are they averages of the performances of the tests throughout.

*Professor Goss.**—With respect to those presented for the Snow engine, I would say that the cards were simultaneously taken, and hence they represent conditions at the given instant. It is, therefore, not the same charge through the engine.

* Author's closure, under the Rules.

No. 855.*

ON THE DESIGN OF SPEED CONES: A NEW FORMULA.

BY JAMES J. GUEST, BIRMINGHAM, ENGLAND.

(Member of the Society.)

SOME time ago the writer was requested to determine the steps on some speed cones for open belts in a case where accuracy was of importance, and upon investigating the methods and formula in use, he was impressed by the amount of "trial and error" involved. This lead to an investigation of the subject which suggested a method which, it is believed, will prove of service to designers of machinery in which speed cones are employed.

The best of the methods examined appeared to be the graphical one due to Reuleaux, but the construction of the necessary curves is very difficult and affords ample scope for any errors towards which the draughtsman may have an inclination. These errors would, however, be lessened if the final curve were at once plotted from its equation, but such a course is strongly militated against by the amount of labor involved.

As the problem arises in practice the distance, a, between the shafts is given, and also the desired speed ratios, k_1, k_2, k_3, . . . k_n, which are usually in geometric progression. Let each ratio be greater than unity, the pulleys being reversed if a ratio less than unity is required. There will also be some structural limitations as to size of pulleys, which, however, need not concern us here.

Let x (Fig. 245) be one of the smaller pulley diameters, so that kx is the diameter of the corresponding pulley on the other shaft.

Then the length of the belt is

$$l \equiv \frac{\pi}{2}(k+1)\,x + \varphi\,(k-1)\,x + 2a\,\mathrm{Cos}\,\varphi \quad . \quad . \quad . \quad . \quad (1)$$

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

where φ is the angle which the belt makes with the line joining the centres of the pulleys.

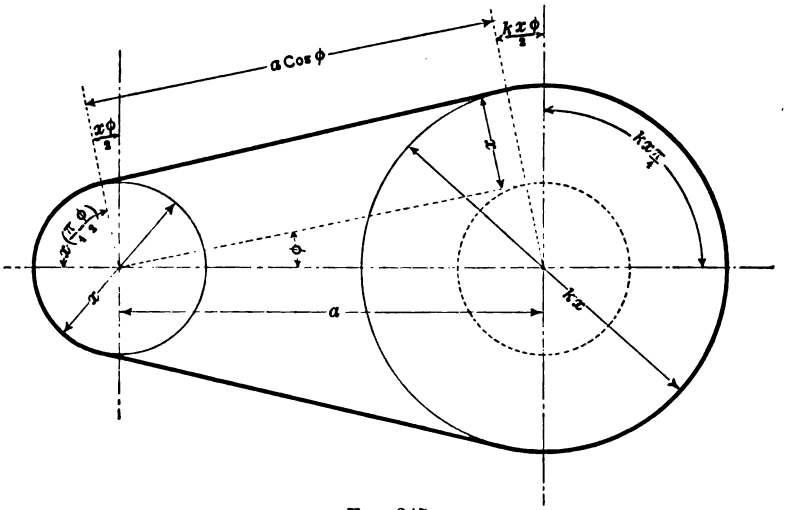


FIG. 245.

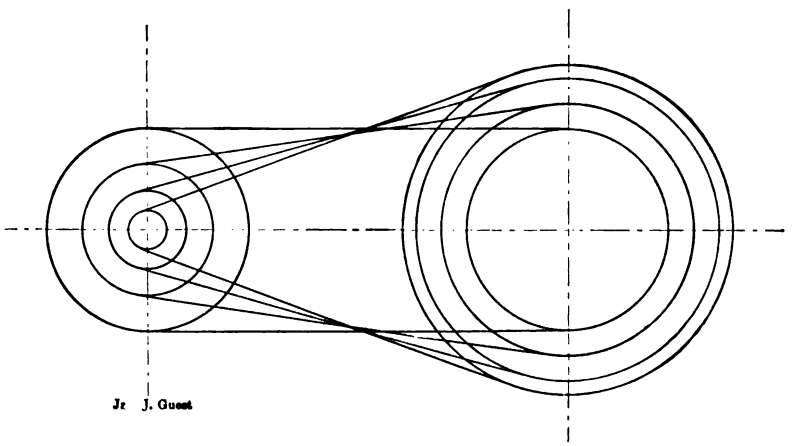


FIG. 246.

Now, if we write Δ for the difference of the pulley diameters, we have

$$\Delta = (k - 1)\, x,$$

$$\text{and} \quad \sin \varphi = \frac{\Delta}{2a} = \frac{\Delta}{b}$$

if we write b for $2a$.

Expand φ and Cos φ in equation (1) in terms of sin φ, and substitute

$$\frac{\Delta}{b} \text{ for } \sin\varphi, \text{ and } \frac{\Delta}{k-1} \text{ for } x, \text{ and we have}$$

$$l = \frac{\pi}{2}\cdot\frac{k+1}{k-1}\cdot\Delta + \Delta\left\{\frac{\Delta}{b} + \frac{1}{6}\frac{\Delta^3}{b^3} + \frac{3}{40}\frac{\Delta^5}{b^5} + \cdots\right\}$$

$$+ b\left\{1 - \frac{1}{2}\frac{\Delta^2}{b^2} - \frac{1}{8}\frac{\Delta^4}{b^4} - \frac{1}{16}\frac{\Delta^6}{b^6} \cdots\cdots\right\}$$

$$\therefore\ 2(l-b) = \pi\cdot\frac{k+1}{k-1}\Delta + \frac{\Delta^2}{b} + \frac{1}{12}\cdot\frac{\Delta^4}{b^3} + \frac{1}{80}\cdot\frac{\Delta^6}{b^5} \quad . \quad . \quad . \quad . \quad (2)$$

This series is always convergent, and in practical cases the values of the terms rapidly diminish, so that we may neglect terms of the fourth and higher orders of Δ. This leaves us with a quadratic for the determination of Δ, which equation is

$$\Delta^2 + Qb\Delta - Pb = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

if we write $\quad 2(l-b) = P,$

and $\quad \pi\frac{k+1}{k-1} = Q.$

One solution is negative and the other is

$$2\Delta = -Qb + Qb\left(1 + \frac{4P}{Q^2b}\right)^{\frac{1}{2}},$$

and as the second turn under the radical is small in practice, we can expand as follows:

$$2\Delta = Qb\left\{-1 + 1 + \tfrac{1}{2}\cdot\frac{4P}{Q^2b} - \frac{2P^2}{Q^4b^2} + \frac{4P^3}{Q^6b^3}\cdots\right\}$$

$$\therefore\ \Delta = \frac{P}{Q} - \frac{P^2}{Q^3b} + \frac{2P^3}{Q^5b^2}\cdots\cdots\cdots$$

and we have

$$x = \frac{1}{k-1}\cdot\frac{P}{Q}\cdot\left[1 - \frac{P}{Q^2b} + 2\left(\frac{P}{Q^2b}\right)^2\right]\cdots$$

$$\text{and}\quad kx = \frac{k}{k-1}\cdot\frac{P}{Q}\cdot\left[1 - \frac{P}{Q^2b} + 2\left(\frac{P}{Q^2b}\right)^2\right]\cdots \quad \Bigg\} \quad . \quad . \quad . \quad (4)$$

as the pulley diameters, when $P = 2(l - b)$ is the same for the whole series, and $Q = \pi \frac{k+1}{k-1}$ is different for each speed ratio.

For equal pulleys we have $x = kx = \frac{l-b}{\pi}$, either directly from the figure or from equations (4).

Hence, to design the speed cones, select the diameters of the pair of steps likely to cause most trouble by interfering with parts of the machine, or for other reasons; then find P from equation (3), where

$$P = \pi \frac{k+1}{k-1} \Delta + \frac{\Delta^2}{b},$$

and determine the other pulley diameters for the various values of k from equations (4). Or P may be selected at starting and all the pulley diameters determined by equations (4).

Thus the method is direct, and no "trial and error" is required.

Some idea of the dimensions of the errors involved in any special case should always be obtained, as unless the belt is very nearly equally tight upon each step, it will rapidly become slack upon some of the steps and cause that species of trouble which leads to the construction of such devices as are occasionally seen in the feed motion of lathes.

Some idea of the errors will be obtained in the calculation itself by observing the importance of the term $2\left(\frac{P}{Q^2 b}\right)^2$ in equations (4). We have also neglected terms in equation (2), which gives us the value of l in terms of Δ, and from it we see that the belt, which fitted over a pair of equal pulleys, would be stretched an extra amount $\frac{1}{24}\frac{\Delta^4}{b^3} - \frac{1}{160}\frac{\Delta^6}{b^5}$, when placed upon another pair.

Should these terms be so large that a correction is advisable, the best mode of correction is to find the length of the belt for the various steps of the cones by calculation, using equation (2), and if the lengths are found to vary so much that a correction should be made, differentiate the equation (2), and we have as the correction for Δ,

$$\delta\Delta = \frac{\delta l}{\frac{\pi}{2}\left(\frac{k+1}{k-1} + \frac{2\Delta}{b} + \frac{1}{3}\frac{\Delta^3}{b^3}\right)}$$

when δl is the variation of the calculated belt length and Δ has its uncorrected value.

Hence the corrected pulley diameters are

$$x - \delta x = \frac{\delta \Delta}{k-1}$$

$$= x + \frac{1}{k-1} \cdot \frac{\delta l}{\frac{\pi}{2} \cdot \frac{k+1}{k-1} + \frac{2\Delta}{b} + \frac{1}{3}\frac{\Delta^2}{b^2}}$$

and $k\,(x - \delta x)$.

To illustrate the method, let us take as an example which will afford larger errors than are ever likely to occur in practice, the case of speed cones on shafts 25 inches apart, the speed ratios to be 1, 2, 4, and 8, and the equal pulleys 12 inches in diameter.

First calculate P.

$$P = \pi \cdot \frac{k+1}{k-1}\Delta + \frac{\Delta^2}{b^2} - \cdot$$

$$= \pi \cdot \frac{k+1}{k-1} \cdot k - 1 \cdot x$$

$$= \pi \cdot (k+1)x$$

$$= 24\pi = 75.3984''.$$

Let $k = 2 \quad \therefore \quad x = \frac{1}{1} \times 8 \times \{1 - 0.01698 + 0.00058\}$

$$= 7.8688$$

and $kx = 15.7376$

Let $k = 4 \quad \therefore \quad x = \frac{1}{3} \times 14.4 \{1 - 0.05500 + 0.00605\}$

$$= 4.565$$

and $kx = 18.260$

Let $k = 8 \quad \therefore \quad x = \frac{1}{7} \times 18.666 \{1 - 0.09249 + 0.01711\}$

$$x = 2.4655$$

and $kx = 19.724$

Now let us see how much extra stretch the belt would get in being moved from the 12-inch pulleys on to the 8 : 1 speed. In the first case

$$l = 50 + 12\pi$$

$$= 50 + 37.699$$

$$= 87.699''.$$

For the 8 : 1 speed we have from equation (2), since $\Delta = 17.259$,

$$l = b + \frac{\pi}{2} \cdot \frac{k+1}{k-1} \Delta + \frac{1}{2} \frac{\Delta^2}{b} + \frac{1}{24} \frac{\Delta^4}{b^3}$$
$$= 50 + 34\,857 + 2.979 + 0.0295$$
$$= 87.865''$$

and therefore the extra stretch would be $\delta l = 0.166$ inch, or about 0.2 per cent. For the other speeds the extra stretch would be much less.

To correct for this we have

$$\delta \Delta = \frac{\delta l}{\frac{\pi}{2} \cdot \frac{k+1}{k-1} + \frac{2\Delta}{b} + \cdots}$$
$$= \frac{0.166}{2.02 + 0.34 + 0.01}$$
$$= 0.07'',$$
$$\text{and} \quad \therefore \quad \delta x = 0.01,$$

and the corrected pulley diameters are

$$x = 2.455'',$$
$$\text{and } kx = 19.64''.$$

The drawing (Fig. 246) shows the pulleys to scale and illustrates the wide limits within which the method is accurate.

The calculations have been taken beyond practical limits for the sake of illustration. In dimensioning the pulleys the belt thickness is to be allowed for.

DISCUSSION.

Mr. E. H. Lockwood.—The problem of finding diameters of stepped pulleys for open belts has provoked much study and ingenuity, more perhaps than its importance warrants. The following method was devised by the writer several years ago,* and has proved accurate and useful in practice.

Rankine† has shown that the sum of a pair of equal pulleys can be found from the sum of an unequal pair by the approximate formula,

$$D_0 = \frac{D+d}{2} + \frac{(D-d)}{4\pi a} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

* *Yale Scientific Monthly*, October, 1894.

† "Applied Mechanics," p. 458.

in which D_0 = diameter of one of a pair of equal steps.
D and d = diameters of unequal steps.
a = distance between centers.

The exact equation of which the above is a simplification is,

$$D_0 = \frac{D+d}{2} + a\left[\frac{D-d}{a}\cdot\frac{\varphi}{\pi} - \frac{2(1-\cos\varphi)}{\pi}\right] \quad \ldots\ldots(2)$$

in which φ is the belt angle, and $\sin\varphi = \frac{D-d}{2a}$. Formula (2) can be written,

$$D + d = 2D_0 - K'a \quad \ldots\ldots(3)$$

where $K' = \left[\frac{D-d}{a}\cdot\frac{\varphi}{\pi} - \frac{2(1-\cos\varphi)}{\pi}\right]$, a quantity which varies with $\frac{D-d}{a}$. It would not be practicable to compute K' in using formula (3), but it can be found quickly from the following table.

TABLE OF VALUES OF K'.

$D-d$	VALUES OF K'.										D	Belt Angle.
a	0	1	2	3	4	5	6	7	8	9		
0.0	.....	.....	.....	.....	.0002	.0004	.0006	.0008	.0010	.0013	0 to 3	0°– 3°
0.1	.0016	.0020	.0024	.0028	.0032	.0037	.0042	.0047	.0052	.0058	4 to 6	3°– 6°
0.2	.0064	.0070	.0077	.0084	.0092	.0100	.0108	.0116	.0125	.0134	6 to 9	6°– 9°
0.3	.0143	.0153	.0163	.0173	.0184	.0195	.0206	.0218	.0230	.0242	10 to 12	9°–12°
0.4	.0255	.0268	.0281	.0295	.0309	.0323	.0338	.0353	.0368	.0384	12 to 16	12°–15°
0.5	.0400	.0416	.0433	.0450	.0467	.0484	.0502	.0520	.0539	.0558	16 to 19	15°–17°
0.6	.0577	.0597	.0617	.0637	.0657	.0678	.0699	.0721	.0743	.0765	20 to 22	17°–20°
0.7	.0788	.0811	.0834	.0858	.0882	.0906	.0931	.0956	.0981	.1007	23 to 26	20°–23°
0.8	.1033	.1059	.1086	.1113	.1140	.1168	.1196	.1224	.1253	.1282	26 to 29	23°–26°
0.9	.1312	.1342	.1372	.1403	.1434	.1465	.1497	.1529	.1561	.1594	30 to 33	26°–30°
1.0	.1627	.1661	.1695	.1729	.1764	.1799	.1834	.1870	.1906	.1942	34 to 36	30°–33°
1.1	.1979	.2016	.2054	.2092	.2131	.2170	.2209	.2248	.2288	.2328	37 to 40	33°–37°
1.2	.2369	.2410	.2452	.2494	.2537	.2580	.2623	.2666	.2710	.2754	41 to 44	37°–41°
1.3	.2799	.2844	.2890	.2936	.2983	.3030	.3077	.3125	.3173	.3222	45 to 49	41°–45°
1.4	.3271	.3321	.3371	.3421	.3472	.3523	.3575	.3627	.3680	.3734	50 to 54	45°–49°

This method differs from Rankine's in that the exact value is found from a table instead of from an approximate formula. The following facts are of value in solving the problems:

1. The sum of two equal steps is greater than the sum of any two unequal steps.

2. The more unequal the steps, the less their sum.

3. The sums of the different pairs never differ greatly from the sum of the equal steps.

4. The sum of any unknown pair can be assumed with a certain degree of approximation, from the sum of any other pair.

5. Knowing the difference of an unknown pair, roughly, their sum can be found very nearly, and by a second trial, almost exactly.

EXAMPLE.

The problem worked by Mr. Guest is,

$D_0 = 12''$, $a = 25''$. Speeds required 1:2, 1:4, 1:8.

Formula (3) becomes

$$D + d = 24'' - Ka.$$

For speed 1:2. Assume trial sum $= 23.5'' \therefore \frac{D-d}{a} = .31$

$K = .0156 \therefore D + d = 24 - .0156 \times 25 = 23.61''$

$\therefore$ Required diameters are, $\begin{matrix} D = 15.74'' \\ d = 7.87 \end{matrix}$ $\left\{\begin{matrix} 15.737 \\ 7.869 \end{matrix}\right\}$ By Mr. Guest.

Speed 1:4. Trial sum $= 23''$. $\frac{D-d}{a} = .552 \therefore K = .0487$

Hence $D + d = 24'' - .0487 \times 25 = 22.78''$

The diameters are, $\begin{matrix} D = 18.22'' \\ d = 4.556 \end{matrix}$

2d trial sum, 22.78, gives $\begin{matrix} D = 18.24'' \\ d = 4.561 \end{matrix}$ $\left\{\begin{matrix} 18.26 \\ 4.565 \end{matrix}\right\}$ By Mr. Guest.

Our figures here are more correct than those of Mr. Guest.

Speed 1:8. Trial sum $= 22''$. $\frac{D-d}{a} = .684 \therefore K = .0751$

Hence, $D + d = 24 - .0751 \times 25 = 22.12$

2d trial sum $= 22.12$, gives $D + d = 22.10$.

The diameters are $\begin{matrix} D = 19.64 \\ d = 2.455 \end{matrix}$ $\left\{\begin{matrix} 19.64 \\ 2.455 \end{matrix}\right\}$ By Mr. Guest (corrected).

This method is open to the objection of "trial and error." The drawback is not serious, however, since a wide variation in the trial sum makes a slight variation in the result. This is shown by the following results for the ratio 1:2.

Trial sum	$D + d$
24"	23.59"
23.5	23.61
23.	23.625

This shows that a range of one inch in the trial sum makes a maximum error of .035 inch in the first result. A second trial would give the correct result, 23.61 inches, in any case.

If unequal diameters are given, $2D_0$ can be found from equation (3). The method also applies when one diameter, instead of the velocity, is given.

Mr. Carl G. Barth.—Nearly three years ago, while I was still with "The International Schools of Correspondence of Scranton," it fell to my lot to answer a question in the columns of the *Home Study Magazine* in regard to the method of determining the proper diameters of open-belt cone pulleys. Being at that time fully ignorant of the many more or less unsuccessful attempts made from time to time by various investigators to get a simple, satisfactory solution of the problem involved, I attacked the subject in my own way, with an ignorance that proved to be bliss; for, had I stopped to look the matter up and familiarize myself with the existing literature on the subject, the chances are that I should not have accomplished what I did.

As it was, I had comparatively little difficulty in developing formulas that proved eminently satisfactory as regards the results they produced, though they were at the same time rather formidable-looking affairs to the man who does not love algebra and figures. However, having more recently succeeded in simplifying my original formulas, without detracting anything from their practical usefulness, I take the opportunity to lay them before the Society while the subject is under consideration, as their degree of accuracy is far ahead of the formulas developed by Mr. Guest, in which I fail to see any improvement on the formulas of Rankine and Weisbach, which are at bottom identical.

Let

D = The effective diameter of the larger of two corresponding cone steps,

d = The effective diameter of the smaller,

$k = \frac{D}{d}$ = The ratio of these steps, or the ratio of transmission,

D_0 = The effective diameters of two equal corresponding steps,

a = The distance between the centres of the cones,

$$n = \left(\frac{D-d}{2a}\right)^2,\quad A = 1 + \frac{D_0\pi}{24a},\quad m = \left(\frac{k-1}{k+1}\right)^2 \frac{D_0}{2\pi a};$$

then my formulas are

$$D_0 = \frac{D+d}{2} + \frac{an}{\pi} \times \frac{168 - 61n - 2n^2}{168 - 75n} \quad \ldots\ldots\ldots (1)$$

and

$$d = \frac{2D_0}{k+1} \times \frac{A + (5 - 2A)m - 2m^2}{A = \pi m} \quad \ldots\ldots\ldots (2)$$

Formula (2) finds immediate application in Mr. Guest's example, while as a rule formula (1) has to be resorted to first, for the determination of D_0. In Mr. Guest's example we thus have

$D_0 = 12''$, $a = 25''$, $k_1 = 2$, $k_2 = 4$, $k_3 = 8$, and hence

$$A = 1 + \frac{D_0\pi}{24a} = 1 + \frac{12''\pi}{24 \times 25''} = 1.062832,$$

$$5 - 2A = 5 - 2.125664 = 2.874336,$$

$$m_1 = \left(\frac{k_1 - 1}{k_1 + 1}\right)^2 \frac{D_0}{2\pi a} = \left(\frac{2-1}{2+1}\right)^2 \frac{12''}{2\pi \times 25''}$$
$$= \frac{1}{9} \times 0.076394 = 0.008488,$$

$$m_2 = \left(\frac{k_2 - 1}{k_2 + 1}\right)^2 \frac{D_0}{2\pi a} = \left(\frac{4-1}{4+1}\right)^2 \frac{12''}{2\pi \times 25''}$$
$$= \frac{9}{25} \times 0.076394 = 0.027502,$$

$$m_3 = \left(\frac{k_3 - 1}{k_3 + 1}\right)^2 \frac{D_0}{2\pi a} = \left(\frac{8-1}{8+1}\right)^2 \frac{12''}{2\pi \times 25''}$$
$$= \frac{49}{81} \times 0.076394 = 0.046214.$$

We accordingly get:

$$d_1 = \frac{2 \times 12''}{2+1} \times \frac{1.062832 + 2.874336 \times 0.008488 - 2 \times 0.008488^2}{1.062832 + 5 \times 0.008488}$$
$$= 8'' \times \frac{1.087085}{1.105274} = 7.868348'',$$

and $D_1 = k_1 d_1 = 2 \times 7.868348'' = 15.736696''$;

$$d_2 = \frac{2 \times 12''}{4+1} \times \frac{1.062832 + 2.874336 \times 0.027502 - 2 \times 0.027502^2}{1.062832 + 5 \times 0.027502}$$
$$= \frac{24''}{5} \times \frac{1.140367}{1.200342} = 4.560168''$$

and $D_2 = k_2 d_2 = 4 \times 4.560168'' = 18.240672''$;

$$d_3 = \frac{2 \times 12''}{8+1} \times \frac{1.062832 + 2.874336 \times 0.046214 - 2 \times 0.046214^2}{1.062832 + 5 \times 0.046214}$$
$$= \frac{8''}{3} \times \frac{1.191397}{1.293902} = 2.4554'',$$

and $D_3 = k_3 d_3 = 8 \times 2.4554'' = 19.6432''$.

However, in order to bring out more forcibly the smallness of the error of these formulas, let us diminish the distance between the centres of the cones to only 12 inches; that is, make it equal to the effective diameters of the two equal steps, in which case we shall have a really, and not an imaginarily, extreme case.

For the steps whose ratio is to be 8, we then have
$D_0 = 12''$, $a = 12''$, $k = 8$, and accordingly

$$A = 1 + \frac{D_0\pi}{24a} = 1 + \frac{12''\pi}{24 \times 12''} = 1.1309,$$

$$5 - 2A = 5 - 2.2618 = 2.7382,$$

$$m = \left(\frac{k-1}{k+1}\right)^2 \frac{D_0}{2\pi a} = \left(\frac{8-1}{8+1}\right)^2 \frac{12''}{2\pi \times 12''} = 0.096279.$$

Hence

$$d = \frac{2 \times 12''}{8+1} \times \frac{1.1309 + 2.7382 \times 0.096279 - 2 \times 0.096279^2}{1.1309 + 5 \times 0.096279}$$

$$= \frac{8''}{3} \times \frac{1.375992}{1.612295} = 2.275832'',$$

and $D = kd = 8 \times 2.275832'' = 18.206656''$.

The belt length over the two equal steps figures 61.687 inches; over these two extreme steps, 61.699 inches, which is less than 0.02 of 1 per cent. too great.

As a test on formula (1), let us now figure back again to D_0, and see how near we get to 12 inches.

We then have

$$n = \left(\frac{D-d}{2a}\right) = \left(\frac{18.206656'' - 2.275832''}{2 + 12''}\right)^2 = 0.440609,$$

and hence

$$D_0 = \frac{18.206656'' + 2.275832''}{2} + \frac{12'' \times 0.440609}{\pi}$$

$$\times \frac{168 - 61 \times 0.440609 - 2 \times 0.440609^2}{168 - 75 \times 0.440609}$$

$$= 10.241244'' + 1.683004'' \times 1.045708$$

$$= 10.241244'' + 1.75993'' = 12.001174''.$$

Surely, as regards sufficient accuracy, these formulas leave nothing further to be desired; but still, they will not always fill the bill. I have thus recently had a number of cases in which the problem was to find suitable steps for a new cone to be belted to an already existing one. In these cases I have made

use of the tables published by Prof. J. F. Klein in the *American Machinist* for October 22, 1881, which were gotten up for just such cases, rare though they may be.

*Mr. J. J. Guest.**—The fact that two other members of this Society have worked out independent formulæ for the design of speed cones goes to show that the subject is of interest to the engineer.

Mr. Lockwood's method is happily conceived, but I fear that the use of a special table of values, combined with a need for "trial and error"—small though it be—would not be properly appreciated by the normally constituted designer, who loves to have a short, simple formula in his pocketbook. This is what I have endeavored to provide—one of much higher accuracy than is ever practically required, and, at the same time, direct and well adapted for calculation.

Mr. Barth's method appears to be much more ambitious, and, judging from the number of terms it contains, ought to be a close approximation; it is hardly in a form suited for easy calculation, but perhaps that could be remedied.

Mr. Barth seems to doubt the sufficiency of the accuracy of the formula I suggest, but the example I selected is certainly beyond the limit of practice, as the angle of embrace of the smallest pulley in the sketch at once suggests how much the driving power is diminished, and surely an accuracy of one-fifth of one per cent.—the case without the correction—is ample.

The advantages over Rankine's method possessed by the one I suggest are the absence of "trial and error," and accuracy.

There may be some advantage in expressing the formulæ in terms of D_0—the diameter of one of the equal pulleys, instead of in terms of P—twice the circumference of the same. If my formulæ were altered in this respect they would become

$$D_0 = \frac{k+1}{k-1}\cdot\frac{D_0}{2} + \frac{D_0^2}{4\pi a}, \text{ and}$$

$$x = \frac{2D_0}{k+1}\left[1 - \frac{1}{\pi}\left(\frac{k-1}{k+1}\right)^2\frac{D_0}{a} + 2\left\{\frac{1}{\pi}\left(\frac{k-1}{k+1}\right)^2\frac{D_0}{a}\right\}^2\right]$$

* Author's closure, under the Rules.

However, in order to bring out more forcibly the smallness of the error of these formulas, let us diminish the distance between the centres of the cones to only 12 inches; that is, make it equal to the effective diameters of the two equal steps, in which case we shall have a really, and not an imaginarily, extreme case.

For the steps whose ratio is to be 8, we then have
$D_0 = 12''$, $a = 12''$, $k = 8$, and accordingly

$$A = 1 + \frac{D_0\pi}{24a} = 1 + \frac{12''\pi}{24 \times 12''} = 1.1309,$$

$$5 - 2A = 5 - 2.2618 = 2.7382,$$

$$m = \left(\frac{k-1}{k+1}\right)^2 \frac{D_0}{2\pi a} = \left(\frac{8-1}{8+1}\right)^2 \frac{12''}{2\pi \times 12''} = 0.096279.$$

Hence

$$d = \frac{2 \times 12''}{8+1} \times \frac{1.1309 + 2.7382 \times 0.096279 - 2 \times 0.096279^2}{1.1309 + 5 \times 0.096279}$$

$$= \frac{8''}{3} \times \frac{1.375992}{1.612295} = 2.275832'',$$

and $D = kd = 8 \times 2.275832'' = 18.206656''$.

The belt length over the two equal steps figures 61.687 inches; over these two extreme steps, 61.699 inches, which is less than 0.02 of 1 per cent. too great.

As a test on formula (1), let us now figure back again to D_0, and see how near we get to 12 inches.

We then have

$$n = \left(\frac{D-d}{2a}\right) = \left(\frac{18.206656'' - 2.275832''}{2 + 12''}\right)^2 = 0.440609,$$

and hence

$$D_0 = \frac{18.206656'' + 2.275832''}{2} + \frac{12'' \times 0.440609}{\pi}$$

$$\times \frac{168 - 61 \times 0.440609 - 2 \times 0.440609^2}{168 - 75 \times 0.440609}$$

$$= 10.241244'' + 1.683004'' \times 1.045708$$

$$= 10.241244'' + 1.75993'' = 12.001174''.$$

Surely, as regards sufficient accuracy, these formulas leave nothing further to be desired; but still, they will not always fill the bill. I have thus recently had a number of cases in which the problem was to find suitable steps for a new cone to be belted to an already existing one. In these cases I have made

use of the tables published by Prof. J. F. Klein in the *American Machinist* for October 22, 1881, which were gotten up for just such cases, rare though they may be.

*Mr. J. J. Guest.**—The fact that two other members of this Society have worked out independent formulæ for the design of speed cones goes to show that the subject is of interest to the engineer.

Mr. Lockwood's method is happily conceived, but I fear that the use of a special table of values, combined with a need for "trial and error"—small though it be—would not be properly appreciated by the normally constituted designer, who loves to have a short, simple formula in his pocketbook. This is what I have endeavored to provide—one of much higher accuracy than is ever practically required, and, at the same time, direct and well adapted for calculation.

Mr. Barth's method appears to be much more ambitious, and, judging from the number of terms it contains, ought to be a close approximation; it is hardly in a form suited for easy calculation, but perhaps that could be remedied.

Mr. Barth seems to doubt the sufficiency of the accuracy of the formula I suggest, but the example I selected is certainly beyond the limit of practice, as the angle of embrace of the smallest pulley in the sketch at once suggests how much the driving power is diminished, and surely an accuracy of one-fifth of one per cent.—the case without the correction—is ample.

The advantages over Rankine's method possessed by the one I suggest are the absence of "trial and error," and accuracy.

There may be some advantage in expressing the formulæ in terms of D_0—the diameter of one of the equal pulleys, instead of in terms of P—twice the circumference of the same. If my formulæ were altered in this respect they would become

$$D_0 = \frac{k+1}{k-1} \cdot \frac{D_0}{2} + \frac{D_0^2}{4\pi a}, \text{ and}$$

$$x = \frac{2D_0}{k+1}\left[1 - \frac{1}{\pi}\left(\frac{k-1}{k+1}\right)^2 \frac{D_0}{a} + 2\left\{\frac{1}{\pi}\left(\frac{k-1}{k+1}\right)^2 \frac{D_0}{a}\right\}^2\right]$$

* Author's closure, under the Rules.

No. 856.*

THE AUTOMOBILE WAGON FOR HEAVY DUTY.

BY ARTHUR HERSCHMANN, NEW YORK CITY.

(Associate Member of the Society.)

IT can be easily proven that the progress of civilization made by all nations has been closely interwoven with the progress of transportation. In olden days men were well satisfied to live, grow, and end their days wherever destiny planted them. There they established themselves, contented with the pursuits of life which were within easy reach, looking to Nature for their maintenance, and buying and trading with their immediate neighbors, and within narrow bounds. It would be outside the scope of this paper to discuss whether life was then less comfortable than it is to-day, and whether the few commodities then obtainable were insufficient to make existence enjoyable.

At the present day our needs are considerable, varied, and ever increasing. It is no exaggeration to state that many a person's happiness is marred for a good many hours if an express package containing personal goods, coming from a great distance, should not arrive on the hour.

We all know how an improvement in the facilities for rapid passenger transit shifts the centres of districts where people congregate to manufacture, and the districts where they gather to live. Towns prosper or decay according to transportation facilities, and the value of real estate is seriously affected by them.

The manufacturer and the farmer know what it means to buy and sell where the opportunity is greatest, and how important the item of a quick, safe, and economical transportation of their goods has become at the present day, when the fluctuations in the value of raw material have become an ever-increasing factor in the cost of the finished product.

---

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

No. 856.*

THE AUTOMOBILE WAGON FOR HEAVY DUTY.

BY ARTHUR HERSCHMANN, NEW YORK CITY.

(Associate Member of the Society.)

IT can be easily proven that the progress of civilization made by all nations has been closely interwoven with the progress of transportation. In olden days men were well satisfied to live, grow, and end their days wherever destiny planted them. There they established themselves, contented with the pursuits of life which were within easy reach, looking to Nature for their maintenance, and buying and trading with their immediate neighbors, and within narrow bounds. It would be outside the scope of this paper to discuss whether life was then less comfortable than it is to-day, and whether the few commodities then obtainable were insufficient to make existence enjoyable.

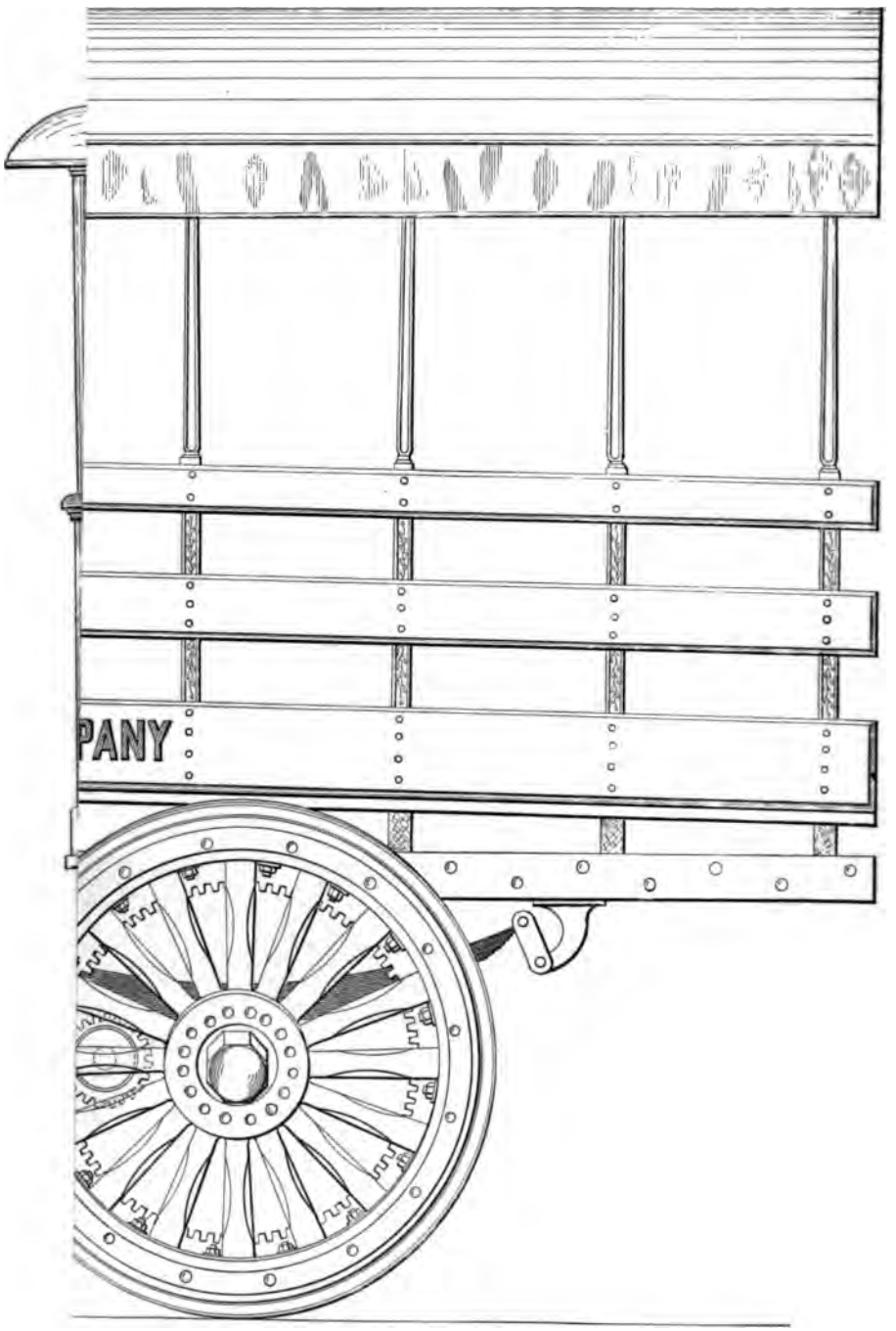
At the present day our needs are considerable, varied, and ever increasing. It is no exaggeration to state that many a person's happiness is marred for a good many hours if an express package containing personal goods, coming from a great distance, should not arrive on the hour.

We all know how an improvement in the facilities for rapid passenger transit shifts the centres of districts where people congregate to manufacture, and the districts where they gather to live. Towns prosper or decay according to transportation facilities, and the value of real estate is seriously affected by them.

The manufacturer and the farmer know what it means to buy and sell where the opportunity is greatest, and how important the item of a quick, safe, and economical transportation of their goods has become at the present day, when the fluctuations in the value of raw material have become an ever-increasing factor in the cost of the finished product.

---

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.



AMERICAN BANK NOTE CO., N.Y.

Before the advent of the railroad overland transportation was limited to the public highways. Washington maintained that the future prosperity of the country would depend on *more* horses and national roads, and it can be well said that his prediction has been fulfilled if we only substitute for the word "horse" the words "motive power." When, long after Washington's days, the locomotive appeared, the prevailing idea was that there would be little further use for horses and that all traffic would soon be handled by steam roads. It was different. The fact became apparent that traffic begets traffic, and that the increased opportunity which the railroad presented stimulated local enterprise and necessitated the employment of more horses and wagons to ply to and from railroad stations. It can be safely stated that the amount of merchandise hauled by horses on our streets and over short distances is as great in the aggregate as that carried by the railroads over long distances.

The advent of the bicycle and of the electric trolley car brought out renewed predictions of the disappearance of the draught horse, and yet statistics show that the number of horses in use has so far been little affected.* However, with the advent of the motor carriage this decrease may now be accelerated, to give way to a greater diminution in the number of horses used. Some enthusiasts have already predicted that it will be only a few years before there will be no horses on the streets. This sanguinism is not justified. The horse will continue to remain man's best friend among the brute creation as a saddle horse, and will probably never be wholly displaced in the propulsion of fancy carriages, but there can be little doubt that the motor freight vehicle has come to stay and will eventually supersede the horse as a beast of burden. It is only a question of some time and evolution before it will become a universal institution and of the greatest importance to transportation interests.

The motor wagon presents a problem which should admit of no prejudice. It is a case free from sentiment, and merely influenced by economic considerations. The elements constituting in principle a successful motor vehicle were known and experimented with by enterprising engineers some eighty years

* Horses in the United States, on January 1, 1893, about 16 millions, on January 1, 1899, decreased to about 14 millions.

ago. The reasons why those experiments did not lead to results are not far to seek. It was then the time of railroad development, and the new competition from the railroad did not encourage costly experiments in a competitive line. Furthermore, the machinery used in the motor carriages was in a crude and undeveloped state. The revival of the movement, which may be said to have begun not more than ten years ago, has met with a great deal of indifference and prejudice. It has been contended that these wagons would frighten the horses, while we can say to-day that most horses soon become accustomed to the peculiarities of their new competitor. Most of this opposition has come from prejudiced quarters; many of the opinions have been volunteered by persons who had never ridden in a motor carriage, and whose remarks were intended for consumption by the home circle. The advantages of any kind of self-propelled vehicles are patent to any one who stops to give the matter unbiased thought. One has only to think how quickly a motor wagon with its reduced length can thread its way through crowded thoroughfares, and how it thus saves road space which is at present occupied and made dangerous by the oftentimes erratic horse.

The smell caused by the worst of the present-day vehicles is not as bad as the smell emanating from horses with which we have to put up in hot weather.

It may be contended that the heavier weights supported by the largest types of motor wagons will damage the roads, but this can be proven to be a fallacy, since even if such damage did occur it would be more than outbalanced by the pounding and tearing action of the horses' hoofs.

One of the necessities for the successful running of motor vehicles, for some time to come, will be a good road surface, and those responsible for the maintenance of public roads could well afford to encourage the new movement, seeing that by the use of motor wagons a considerable saving will be effected in the matter of street cleaning, let alone the improvements in the hygienic condition of the roads.

The matter of safety has often been doubted, and, while we will consider it later when studying the characteristics of differerent systems of motor wagons, it may here be said that statistics have already shown the new vehicle to be far safer from accidents than the horse-drawn vehicle.

At times the horse will stop of its own sweet will, and refuse to budge, but, in case of emergency, using his best efforts he could seldom pull up from full speed inside of less than thirty yards. It necessarily takes time to communicate the driver's will to the horse's brain, and from there to the horse's muscles. A motor wagon, on the other hand, can be quickly stopped, as powerful brakes are within easy reach of the driver, whose intelligence alone is challenged in case of emergency. In addition, the driver of the motor wagon will have a clear view of the road ahead without being perched high in the air. It is very difficult to avoid an accident with a horse-driven wagon should the pole chain break, and it is naturally most likely to break when it is most wanted, *i.e.*, when suddenly pulling up.

There is another important item which is strongly in favor of the motor wagon as compared with the use of horses. Horses are dependent on the weather. Flies molest them in summer time, and the driver is often led to believe they are sick or tired, and will naturally slacken up for fear of straining them. Climbing a steep hill, he will often get off the wagon to save his horses, and it is evident that all this interferes with economical transportation.

We have briefly touched the matter of brakes, and this really is the nucleus of the speed question. We need only consider the speed of modern railway trains and ask ourselves whether such a speed could be safely maintained without the use of air brakes, to approach the speed question of motor wagons. It is an easy matter to provide for powerful brakes on a motor wagon, and the propelling motor lends itself in many cases as a very powerful second brake. We have found that a load of three tons on a motor wagon, running at a speed of eight miles, could be pulled up in eight yards, a performance which could never be obtained with horses. It may have escaped the notice of the onlooker that when we speak of an 8-mile gait with horses it should be asked, how long can they keep it up, and then it should be considered that it would probably only approximate a 5-mile gait of a motor wagon, which latter never gets tired, runs evenly, and is ready to do work as long as we provide fuel; and, further, is satisfied to remain where we leave it when put out of commission. The latter consideration is an economic advantage not to be overlooked in the operation of motor wagons.

Taking up the different propelling agencies which have been experimented with so far, we find that almost every known motive power has been tried. Steam was employed as early as 1820, and such wagons were built by the world-renowned Ericsson and Tangyes in England, and even James Watt is said to have constructed a steam carriage. With the low steam pressures then available, poor roads, and difficulties with unreliable material and workmanship, it is not surprising that the matter was allowed to drop. The next experiments were in the line of oil engines, followed by electric vehicles, compressed air, carbonic acid, and the revived steam carriage.

Naturally, in this country, leading the world in electrical subjects, expectations were greatest with electric vehicles. The electric equipment renders a vehicle clean and easy to operate. These vehicles can be made to answer the requirements of running on smooth city roads. The suitable commutation of battery cells provided in these vehicles, effected through interconnection of contacts on the "controller," affords, together with the series and multiple arrangement of the motor, some flexibility in the power and speed conditions of the machine. There are, however, inherent disadvantages to the use of batteries, which grow prohibitive in a motor wagon intended to carry heavy weights over a long distance. It is common experience that on rough roads the punishment is more than the batteries can stand, and where we have a case of heavy loads to be carried, necessitating the use of steel tires, we can well say that at this phase of the evolution the battery makes the electric truck an impossibility. It would lead too far to enter minutely into the matter of cost of operating electric wagons, but it may be stated that the best traction cell has only a capacity of about seven watts per pound of its weight, and with this as a basis, one can soon calculate how much dead weight a wagon would have to carry to propel a big load over a long distance with one charge. The "maintenance" of batteries, apart from the actual cost of charging, is seldom spoken of, though it is perhaps the most serious item.

Next to the electric wagon we saw the auto-truck, or, better still, heard about it. It was stated that compressed air trucks would soon be operated in considerable numbers. Now, while it cannot be denied that compressed air would make an ideal motive power, we have still to look for a complete revolu-

tion in the construction of light storage tanks to render this power available for trucks, granting that other disadvantages inherent to the use of compressed air can be practically overcome. Weight for weight, stored electricity lends itself more readily to the propulsion of wagons, since it will, as it were, "keep pressure" until it becomes well-nigh exhausted, while the air pressure falls gradually as the air is drawn from the storage tanks. The tank weight per cubic foot of air is about 85 pounds; the air itself weighs 11 pounds, and at 2,000 pounds per square inch, represents 0.27 horse-power hours. To heat the air, considerable weight has to be carried.

Carbonic acid has also been proposed for the operation of wagons, but it suffers in common with compressed air, and, moreover, the raw material to be compressed is by no means cheap.

It has been proposed to compress illuminating gas, and use it for the propulsion of gas motor wagons. While the radius of the operating district for such a vehicle would be evidently greater than with the other storage systems, seeing that about 18 cubic feet of gas at *normal* pressure would already give one brake horse-power, whilst about as many cubic feet of air of 200 pounds pressure, or of carbonic acid of a high pressure, are required. This system has, however, the disadvantage of seriously complicating the mechanism.

A great deal of experience has been gained with oil motor wagons, though chiefly in the line of light pleasure vehicles; and France, in which country there are many thousands of these vehicles plying, has led the world in their exploitation.

As regards freight vehicles, however, no important results have been obtained with the use of explosive motors. A motor wagon, on account of its great weight and peculiarity of operation, must have an abundant supply of power; so great, in fact, as to puzzle the uninitiated observer. We find that a load which can be easily negotiated by one horse, calls for a power equipment equal to about 14 horse-power on the part of a motor wagon. While we commonly understand that 1 horse-power equals 33,000 foot-pounds per minute, we should consider how great the work of a horse can be for a short while on the race track, or when he becomes infuriated and with "blind staggers" dashes into destruction. A horse, when required to pull a heavy load out of a difficult position, will not only jerk and lift the

shaft so as to bring the wheels out of a rut and get them on a level, but will momentarily exert power which has been, by means of a dynamometer, shown to be adequate to a performance of what we commonly call 14 horse-power. Some people, in fact, assert that the horse can for an instant by far exceed the latter figure, but we may be well contented to accept this as a basis of calculation for the supply of motive power. The same horse having pulled his wagon out of the difficult position, is able to modify the output of his energy, propelling the wagon at a good rate of speed as soon as he reaches better ground. The "speed-changing device," which should as nearly as possible emulate the peculiarity of the horse's muscular system, is still the greatest problem with designers of oil wagons. The most ingenious devices have been already tried with a view of filling this gap, and with more or less success; they consist chiefly of such elements as spur and bevel gears, belts, chains, shifting wheels, expanding pulleys, or combinations of some of the above devices with brakes and clutches. Even hydraulic and electric combinations have been unsuccessfully tried. An oil engine to run a motor wagon cannot well be designed to vary in speed, at least not in a wide range, and be satisfactory in other respects. Its construction necessitates its running at a constant speed, whilst the speed requirements of the wagon wheels to which it is geared up are ever changing. Clutch and shifting gear wheels are, therefore, essential parts of every oil motor wagon, and their operation, on account of the impact of the moving masses, often gives rise to serious trouble. Non-reversible, an oil engine is by no means a flexible motor. It will not start under load, and when it is in running condition it is very dependent on an even influx of its explosive mixture, and is liable to come to a dead stop without warning when its capacity has been suddenly overtaxed. Anybody who may have gotten stuck with a motor vehicle while ascending an incline will appreciate these remarks. In such a case it will occur to him that it is very difficult at the same time to release the brake and start the wagon "ahead" on slow speed. It need hardly be said that an oil vehicle is dependent on the weather, inasmuch as the action of the carburettor is influenced by the atmosphere. This latter idea leads to the subject of perfect or imperfect combustion and its attendant outward sign, which is an evil-smelling exhaust. The good behavior of large oil engines

on heavy trucks after an extended period of running has not yet been satisfactorily proven, and the deterioration due to the pounding on the frame is a serious drawback. The general use and handling of large quantities of gasoline at this stage of evolution of the oil engine is by no means free from risk of explosion, and there is some danger of *affecting perishable goods and foodstuffs* by the odor, which would naturally permeate them, particularly while standing at the express company's depot.*

Having thus described the difficulties with which the electric and oil wagons have to contend, we may devote ourselves to the steam wagon, with which, undoubtedly, important results have already been obtained. Before entering into the technical details of the steam wagon, it would be well to consider the problem from an economic and managerial point of view, since it seems that with the best constructed motor wagon, propelled by any power, the technical aspects are still subservient to the commercial. We have found the steam wagon superior to its competitors for the following reasons:

1. It has the greatest load and mileage capacity, or, in other words, radius of action.

2. Its operation is independent of charging stations, and supplies necessary for the operation of the wagon can be easily procured and taken aboard quickly.

The operating expenses in the case of an electric (or, in fact, of any power storage system) vehicle grow to be prohibitive as soon as a certain ton mileage capacity is exceeded, tending to keep such an electric wagon small in size.

In the case of an oil wagon such economic restrictions to the size do not exist, and the objections to an oil wagon of large capacity are more by virtue of difficulties in operation.

With steam the case is altogether different. The tendency is here to build a large wagon, since with a steam wagon the weight of the machinery to be carried does not grow *even* in an arithmetical ratio to the carrying capacity. One advantage found in the operation of a large steam wagon may not be apparent to the casual observer. In the case of the horse-drawn

* If it were possible to make a practical success of an oil motor wagon, using crude oil, no doubt the scope of the oil motor wagon for heavy duty would be considerably increased.

wagon one has to discriminate in loading it with goods which are to be delivered only on the exact route covered by the wagon, seeing that the *daily* carrying capacity of a horse is limited, while in the case of a large steam wagon this would be less important, since, as will be shown later, the percentage of operating expense due to the *actual cost of propulsion proper* is infinitely smaller than in the case of traction with animal power.

When I submitted my first report to the Adams Express Company, to whom I stand in the relation of mechanical engineer, in 1898, on the progress made on motor wagons, it was my opinion, that there had been, up to that date, nothing constructed likely to form a suitable substitute for a horse-drawn wagon but a steam-propelled vehicle. President L. C. Weir then remarked that there seemed to be less difficulty in constructing such a wagon to do the work of two horses than to construct a successful substitute for a one-horse wagon, and I believe that the data, which I intend to give later on, will convince you of the correctness of this opinion.

Construction.

As regards the construction of steam-propelled wagons, we find that in spite of the fact that steam equipment has been known for many generations, and wagon building has been going on for thousands of years, comparative success has only been obtained within the last few years. Messrs. Scotte, and Serpollet De Dion in France, were the first to revive the movement, but in the last few years more progress was made in England, in which country the best steam wagons, so far, have been produced. Easy riding wagons have been constructed for many years, and boilers, steam connections, and engines do not give much trouble on rock-bottom foundations, but when we attempt to locate engine and boiler on a wagon, which latter they have to drive without suffering from the shock of the locomotion on rough roads, new complications arise which are infinitely more important and troublesome than most people believe who have devoted themselves to the study of this subject. We find early attempts to effect this compromise in a steam vehicle built by the Ericssons in England in 1830, who placed a vertical engine on the rear of their vehicle, and coupled it up with a long springy connecting rod to the front wheels, which acted as drivers, thereby prevent-

ing excessive shock being transmitted from the wheels to the engine.

Wheels in themselves are far more important problems than is generally believed. My opinion is, that at the present day no form of rubber tire will give satisfaction on a commercial wagon intended to carry a net load of, say, one ton or more. The rubber tire is not only expensive, but gives poor satisfaction under the combined action of great weight and speed. Attempts have been made to retain the desirable features of a rubber tire, protecting the latter with a tire shield of steel, dating back as far as the early 70's, but it would seem that such combinations are just as troublesome to maintain. Steel tires, if properly applied to stiff wooden wheels, have been proven to stand most severe work, and they afford the advantage of strengthening the wheels very considerably. It is my opinion, that well-constructed springs of ample proportions are alone the means to lessen the shock to which a wagon wheel is subjected. In the case of dished or cored wheels, which I consider to be best adapted for heavy work, a steel tire is indispensable, since it binds the wheel together and prevents the spokes from being torn out when striking an outer obstruction. There is considerable divergence of opinion as to whether a comparatively narrow tire or a wide tire should be used, whether the wheels should be small or large, and whether the front or hind wheels should be driven or steered. While it is a fact, even in the case of motor-propelled vehicles, that the width of the tires should be smaller on hard roads and greater on soft roads (but not on sandy roads or in snow), I think that in the case of steam wagons the total width of the tires in inches should be at least twice the number of gross tons carried when small wagons are concerned, say of a capacity of two tons of net load; this coefficient of two to decrease, in the case of very heavy wagons, to one, and even under.

The reasons why small driving wheels seem to be exclusively used on motor wagons are mostly that it is difficult to design large wheels which will stand such severe strains as motor-wagon wheels are subjected to. In this case the spokes of the wheel not only support the load, as in a horse-drawn vehicle, but they are more or less affected by the action of the driving power, and, moreover, there is also a tendency to twist them. With the ideal wagon wheel the power should be applied directly where

the wheel touches the ground. In reality we drive onto a spur wheel, or chain wheel, concentric with the wheel, but, of course, of a smaller diameter, and such an arrangement makes it desirable that the wheel should also be small. Another reason making small wheels desirable lies in the requirements of the wagon, and the working of a high-speed motor. In other respects it seems to me that a large driving wheel, say of 4-foot diameter, will answer much better than a 3-foot wheel, such as has been almost exclusively applied to steam wagons. I consider that not only will a 4-foot wheel allow of a more powerful starting torque, but it will also save the driving gear, seeing that it does not sink in as deep as a small wheel when it passes over a depression in the road.

The argument presented by advocates of the "front-driving" system is, that the wagon will steer a straighter course when the wheel strikes an obstruction, for the reason that the front wheels, in striking, tend to run over the obstruction, instead of being forced aside. I have seen such wagons steered behind and in front, and my opinion is, that any advantage of front driving is more than outbalanced by the disadvantages introduced in connection with awkward location of the machinery. One of the early steam wagons was driven by all four wheels, and if such driving could be practically effected, I think it would prove an excellent feature of a wagon. There are, roughly speaking, two steering systems used—steering with a fifth wheel, and, secondly, steering with pivoted axle ends. It would seem that the fifth-wheel steering arrangement is more adapted for heavy work, leaving the wagon axle unbroken. In reality, this system cannot be as satisfactorily applied as steering with pivoted axle ends. To effect the steering of heavy wagons, spur gearing of suitable purchase has to be used, or a worm and worm wheel device. The latter seems to answer in one of the best designed wagons, but I do not consider it as desirable as steering by means of spur gearing, since it locks the gear, and, besides, causes a severer strain on the wagon in case the front wheels strike an obstruction. In rounding a curve, the inner wheels necessarily describe a smaller circle than the outer wheels. To make this practicable, the steering device has to be correctly designed, and the two driving wheels have either to be driven by independent motors, or have to be linked together by means of a compensating gear, or, as it is often called, "Jack-in-the-

box." It will be found that in a heavy wagon, particularly one using dished wheels, this driving and the arrangement of the compensating gear are rather troublesome, and that there is still great scope for improvement in this connection. The transmission gear, forming the link between the rear wheels and the engine, which is almost invariably in front of the driving wheels, I think can only be reliably effected by means of accurate spur wheels, immersed in an oil bath. With a steam wagon it is not necessary to use any kind of a clutch while running, seeing that the steam engine is a very flexible prime mover. Nevertheless, I think that a speed reduction gear, which can be best provided by means of two sets of spur wheels of varying diameter, one set stationary, the other movable axially on a square shaft, forms a desirable adjunct to the mechanism, to be shifted when the wagon is at rest, so as to increase its traction power, and enable it to negotiate any special hill, or extricate the wagon from a bad position. We cannot deny that, for many years to come, greasy and hilly roads, or deep snow, will be the greatest difficulties to contend with. I attempted on a damp day to take a load of four tons up an incline of about 1 to 20, covered with Belgian blocks, and there was trouble with the drivers racing. The engine was geared 1 to 14, and the wheels were of 3-foot diameter; in my opinion large and heavier driving wheels and a much lower gear would have taken the wagon up. With the slightest turn of the valve, the engine, without difficulty, started, and on account of the poor adhesion and the light machinery ran away before the inertia of the heavy wagon was overcome.

The next question we have to consider is the boiler and engine, machinery with which you are all thoroughly familiar. Among the steam wagons built so far, one can notice a great variety of boiler designs. The desiderata of a suitable boiler for a motor wagon are that it should be of the greatest safety, of small proportion, quick steaming and economic. In addition, it should be of the simplest possible construction, and free from joints likely to work loose by jarring on the road. Pipe boilers, while perhaps a little safer than shell boilers, carrying little water, are, for the same reason, undesirable for the varying demands made of a wagon boiler. There are other objections to small calibre pipes. They are necessarily exposed to intense heat and liable to burn, and without a large dry tank they will make wet steam. A shell boiler, on the other hand, can be made of ample proportions, and,

if well constructed, and watched during its use, should give no apprehensions as to its safety. The water level can be more evenly maintained, and this is a point of some importance. I consider a superheating device an all-round advantage, provided it is correctly applied to the boiler.*

In addition to the engine feed pump, there should always be a second steam-driven pump instead of an injector, which latter, when of small proportions, has not yet been made to give satisfaction on a wagon.

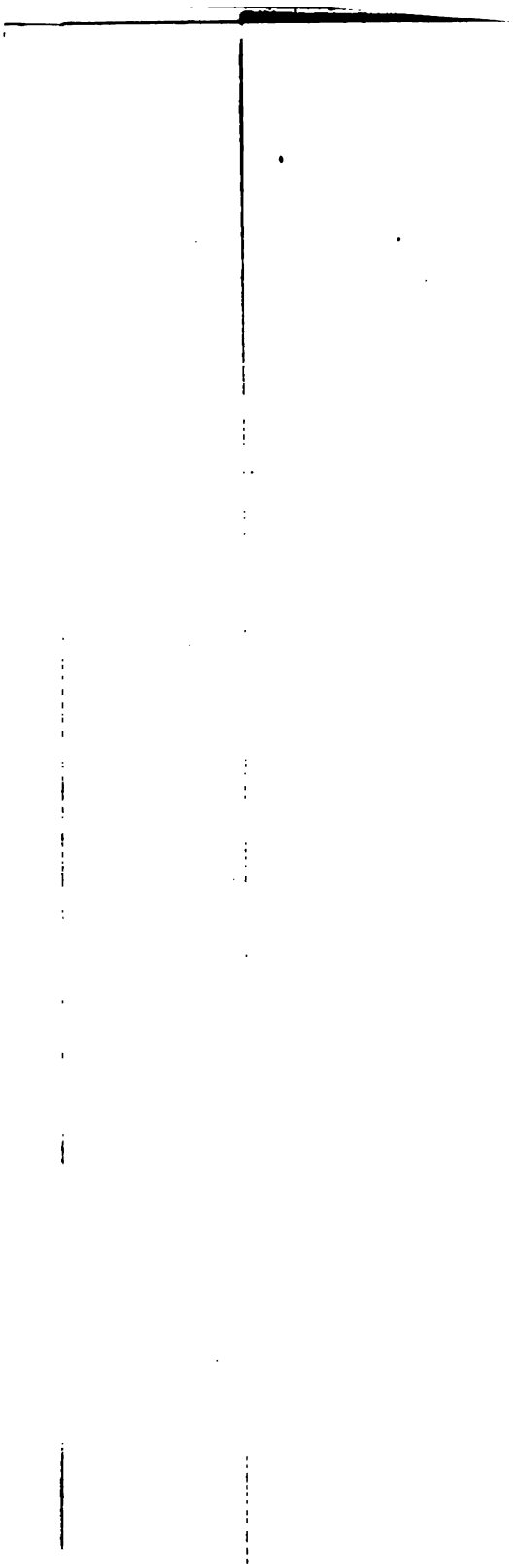
The firing of a wagon boiler can be most easily effected by means of an oil burner, and with a steam governed burner the firing will automatically respond to the requirements. However, in addition to the inherent disadvantages of using oil, it is difficult to maintain the burner in good trim during all kinds of weather, and at this stage of perfection oil burners will "roar" and occasionally give trouble and make smoke. For the latter reasons coal and coke are preferable, being besides cheaper in use. Solid fuel can be conveniently stowed away around the boiler, which latter is generally fixed in front of the wagon, and, if thus located, the stored fuel acts as a compressible safeguard to the boiler in case of a head collision. In using a shell boiler it is found convenient to fire through the boiler top, a system originally introduced into steam-wagon practice with the De Dion boiler.

The difficulties with which one has to contend in the use of steam wagons are, that they will occasionally show a little steam, and during a sharp frost it will be found difficult to prevent a pipe from being frozen up. "Blowing-off" will be found annoying, but this nuisance is largely caused by neglect of the driver and is suppressible.

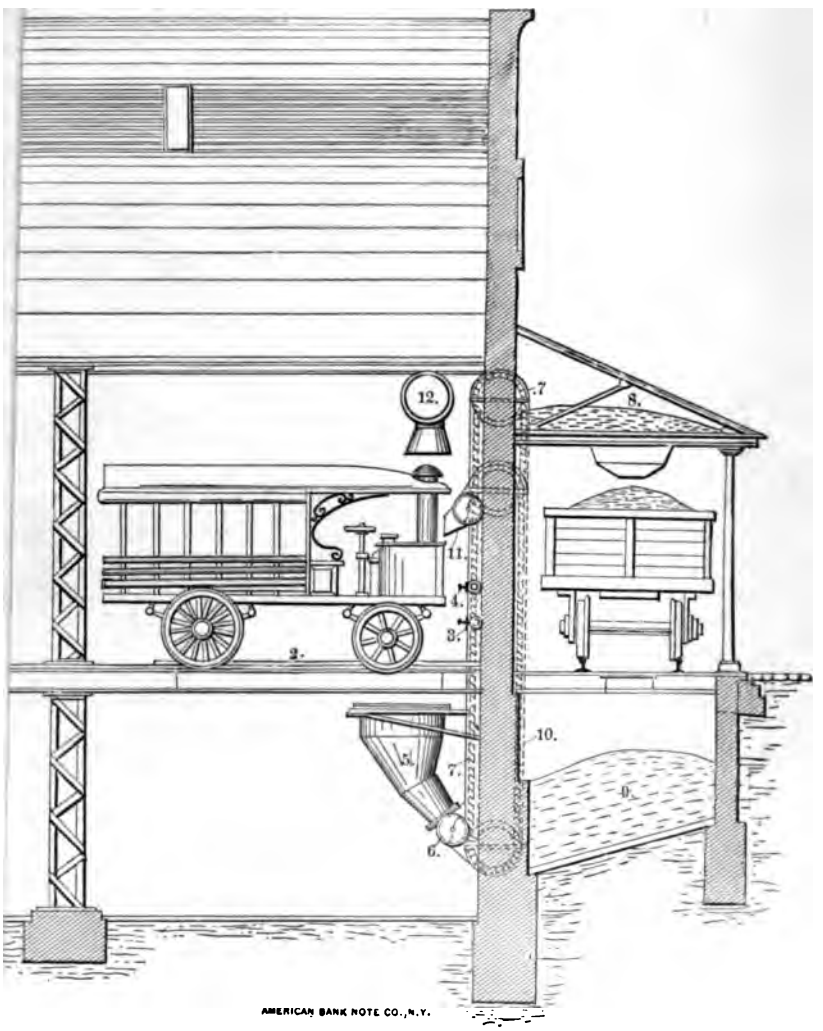
However, these are difficulties which will be overcome in time; using a condenser, there will be practically no visible exhaust in all weathers.

Condensers, however, are by no means desirable constituents of a motor wagon, and I should rather put up with an occasional cloud of steam than with a permanent shower bath due to leaky pipes and the difficulties in running a condenser. It can be well said that difficulties in connection with smoke have already been overcome.

* Figs. 251, 252, 253, and 254 show a boiler, with details of flange and flue connections, designed by the author.



CROSS SECTION



AMERICAN BANK NOTE CO., N.Y.

The engine so far used is in almost every case a compound. If of vertical design it can be located under the driver's seat; while if of horizontal type it can be suspended from the body. In all cases a light and well-designed quick-revolution engine will answer the purpose if it is fitted with a reversing gear, and means to admit high-pressure steam to the low-pressure cylinder. The cylinder ratio should be larger than with stationary practice, seeing that the pressure used is higher, and that a large low-pressure cylinder means a powerful starting moment under live steam, and especial care has to be taken to connect the engine to the frame in an efficient manner. A fly-wheel is sometimes fitted, and then used as a brake wheel, but I deem it unnecessary. As regards the size of the engine I refer to tables appended.

Generally it can be observed that most of the wagons constructed are by far too light to stand the severe strain of their work. As can be seen from the attached tables relating to the running of a steam wagon, their cost of actual propulsion per gross ton is by no means as important an item as, for instance, in an electric vehicle, and one can, therefore, well afford to provide amply for a durable construction. A heavy wagon is just as easy to bring to a standstill as a light wagon, in fact easier, since it may be fitted with quicker acting brakes, which, on account of their severe action, could not be fitted to a light construction. (Figs. 247, 255, and 256 show a steam truck built for the Adams Express Company and designed by the author.)

The idea seems to prevail among some builders of steam wagons abroad that the driver should also effect repairs of the machinery, and that he should adjust the latter to suit himself. I rather think that this theory is against the economical exploitation of such wagons, more particularly if they are used in numbers.

In the latter case a concern would probably house a number of wagons in a shed at a distance from their centre of work which would be too great to stable horses there. Such a shed would have facilities for firing up, taking aboard of hot water and fuel, dropping grates, cleaning, and maintaining, which operations could go on partly from below and without necessarily interfering with the handling of merchandise. (A plan, designed by the author, is appended—Fig. 248—showing the layout of such a depot.)

There would be a foreman capable of adjusting the machinery, or of replacing defective parts, and the driver would merely have to be competent to operate the controlling organs and to take care of his boiler. Radical improvements in the storage of electricity or of compressed gases or relating to explosive engines may yet put the steam wagon in the background; but judging from accomplished facts it is so far the most successful wagon for the economical transportation of heavy loads.

I believe that if the motor wagon is given an unobstructed field and "fair play," it will hold its own and oust the horse-drawn truck in short order. The change must come, and, with perhaps the exception of the harness-maker, everybody will benefit by it. The main trouble seems that educated engineers have so far had little encouragement given them to develop the motor wagon, and that the confused efforts of amateurs and stock-jobbers have drawn the attention of almost everybody to their work, except that of the transportation community, who had no accurate data before them to judge of the practicability of the motor wagon.

Opinions will, however, soon be decided and converge on certain lines, and this once being the case many a designer will be saved from exerting himself in a wrong direction.

In conclusion I would state that the attached tables contain some information gained during an investigation covering the last two years, and made in the interests of the Adams Express Company.

It is only natural that in being permitted to read this paper before this honorable body I should return my thanks to President L. C. Weir, who, in granting permission, said:

"I have no objection to your giving the results of our investigations in the manner suggested, and believe, after all, the outcome will be beneficial to us, for it will challenge the attention of a body of men who are highly capable of understanding the wants of carriers of merchandise, and when given a description of what has been found by you in our interests in foreign countries they will have a foundation for thought, out of which will probably come something vastly better than anything yet exploited, and be a credit to Yankee ingenuity."

APPENDIX.

Comparison of Operating Expenses Taken for One of the Large American Cities Covered by the Adams Express Company's Service.

2-HORSE WAGON AND 3-TON STEAM WAGON.

2 Horses capable of 40 ton miles per day, 300 days.		
Cost of 2 horses ($130), $260.		
Life of horse, 6 years (then worth $30 each) (15% + 5%) $30 + 13	$43	2½%
Wagon cost, $300.		
Last 8 years (12½ + 5%)	51	3½%
Wagon repairs maintenance	96	6½%
Stabling, maintaining, shoeing, rents, etc., per horse and month ($30)	720	46%
Driver's pay per annum	600	40%
Cost of harness ($45), last 5 years, per annum, including repairs	18	1½%
Per annum	$1,528	100%

3-Ton Wagon. 120 ton miles net, 300 days.		
Cost of wagon, $2,500.		
25% interest and depreciation	$625	35%
Driver	800	40%
Gross weight moved, 6½ tons; fuel, 8 lbs. of coke per mile. Present market price, $2.70 per caldron.	100	7%
Repairs, 10% of cost	250	15%
Stores	50	3%
(The figures relating to "cost, depreciation, and repairs" may seem to be high. The author, however, finds that they cannot be much reduced, to serve the purpose of a safe, commercial calculation. On the other hand, cost of water and expenses due to the raising of steam have been left out in the figures. In extreme cases these items might add another 5% to the expense.)		
Per annum	$1,825	100%

	2 Horses.	*3-Ton Wagon.*
Miles per annum	6,000.	12,000
Ton miles net	12,000.	(net) 36,000 (gross) 78,000
Cost per mile	25.46 cents.	15.2 cents.
Cost per net ton mile	12.73 cents.	5.06 cents. (gross) 2.34 cents.
4 trips daily, per trip	$1.27.	8 trips daily, each $0.76.

A comparison between operating expenses of a double and single horse wagon of the Adams Express Company in one of the large American cities showed the following figures:

Cost of Operating Double Wagon Monthly.		*Cost of Operating Single Wagon Monthly.*	
Two horses	$41.68⅓	Horse	$20.84⅙
Wagon	11.45½	Wagon	3.56⅔
Harness	5.02⅔	Harness	2.84
Driver, average	43.05	Driver, average	46.05
Conductor	50.00	Boy, average	15.80
	$154.21¼		$94.10

Cost of operating double wagon would be only 20 to 25 per cent. more expensive than operating one-horse wagons; however, a conductor being required to take the place of the boy helper, the cost of operation exceeds that of the single wagon

by about 60 per cent.; hence it is again seen that considering the high load factor of a single-horse wagon, the two-horse wagon presents more scope for substitution by mechanical means.

Inferences to be drawn from above table.

Horses' capacity limited, *running* expenses are biggest, fixed charges smallest.

Steam-wagon capacity unlimited, running expenses smallest, fixed charges highest.

Actual propelling of load being, therefore, comparatively cheap, lightness of construction is less important than many people think; in fact, reduction of tare weight below a figure consistent with substantial build, using standard material, calls for expensive construction and increases the above items of "fixed charges" and "repairs" *much more rapidly* than what it could possibly reduce operating expenses.

For the same reason steam vans may be housed at a great distance from their place of work—any such runs to and from work are cheap, once the boiler is fired up; firing up called for 70 pounds of fuel on a cold December day, while it took only 8 pounds of fuel per mile to run the wagon; if there were hot water obtainable, such expense could be materially reduced.

Dead Weights and Carrying Capacities of Different Wagons—(Actual Performances).

System.	Dead Weight, lbs.	Useful Load Carried, lbs.	Per cent. of Dead Load.	Daily Capacity.
One horse and wagon. { horse	1,400	3,000	About 100	18 miles.
{ wagon	1,400			27 net ton miles.
Two horses and wagon. { two horses	2,800	4,000	" 66	20 miles.
{ wagon.	3,000			40 net ton miles.
Electric small delivery wagon	3,000	1,000	" 33	20 miles with one charge battery.
Gasoline small delivery wagon	2,000	1,500	" 75	80 miles with one charge fuel.
Gasoline large wagon	4,800	4,000	" 85	
Compressed air on rails	18,000	6,000	" 33	15 miles with one charge.
Two-ton steam wagon	5,400	4,500	" 84	
Three-ton steam wagon	6,700	8,200	" 122	
Four-ton steam wagon	6,500	9,200	" 140	
Wooden freight car	20,000	30,000	" 150	
Steel freight car	39,150	100,000	" 255	

Data for a Wagon for which there is a Great Demand.

We find that a wagon capable of carrying a load of 3 tons and able to mount an incline of 1 : 10 at 2 miles per hour, would be very useful.

Internal friction considered, this would call for power to lift about $\frac{1}{6}$ (equals an incline of 1 : 6) of the gross weight a height of 10,560 feet per hour.

Assuming the gross weight to be $6\frac{1}{2}$ tons, we have:

$$\frac{6.5 \times 2{,}240}{6} \times \frac{10{,}560}{60} \text{ foot-pounds per minute}$$

. . . 427,046 foot-pounds.

In other words: to lift the wagon, irrespective of road resistance, we require 12.93 horse-power. To overcome road resistance (tractive effort assumed to be from 60 to 120 pounds per ton) we require:

$$60 \times 6.5 \left(\frac{2 \times 5{,}280}{60}\right) \left(\frac{1}{33{,}000}\right) \left(\frac{1}{0.60}\right), \text{ . . . } 3.47 \text{ horse-power;}$$

or,

$$120 \times 6.5 \left(\frac{2 \times 5{,}280}{60}\right) \left(\frac{1}{33{,}000}\right) \left(\frac{1}{0.60}\right), \text{ . . . } 6.94 \text{ horse-power.}$$

The wagon must, therefore, have machinery capable of producing, when going up-hill, about a total of 20 horse-power.

Such a wagon should have a boiler of about 100 feet of heating surface exposed to hot gases. Its speed should not be above 6 miles per hour to operate economically. The brakes should enable the driver to stop this wagon when descending the above incline in a distance of about ten yards.

Testing Engine and Gear.

The power of a motor wagon should be always measured in foot-pounds at the rim of the driving wheels; for this purpose the drivers may rest on a revolving roller. The latter is in one with a pulley (*r*) over which a strap is slung, fastened to a dynamometer (*d*) at one end, and carrying a weight (*w*) at the other end. (See Fig. 249.)

The work done at the rim is in foot-pounds.
$2\ \pi\ (r) \times n \times (w - d)$.
r = radius of pulley.
d = reading of dynamometer in pounds.
The friction of engine and gearing can thus be found.

Testing Vehicle.

For the purpose of ascertaining the frictional resistance to motion of the wagon itself, the latter is placed on a measured

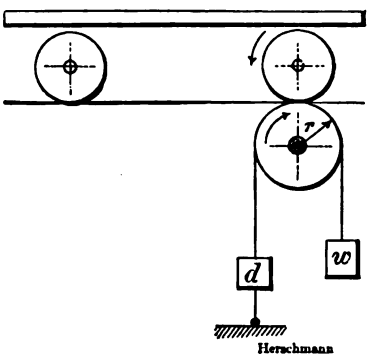


FIG. 249.

incline at A, and permitted to roll down and along the level portion of the road BC (see Fig. 4). While passing the point D, between B and C, and a distance of d from A, its speed measures to be v. We have then: W (weight of wagon in pounds)

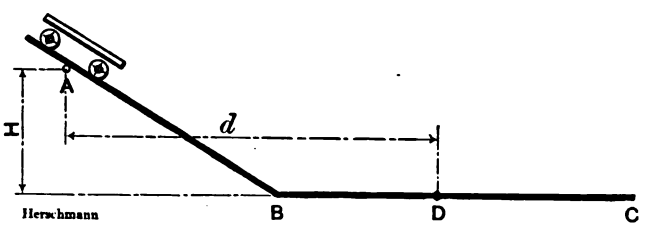
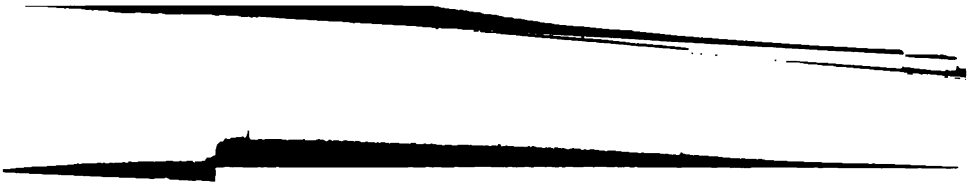
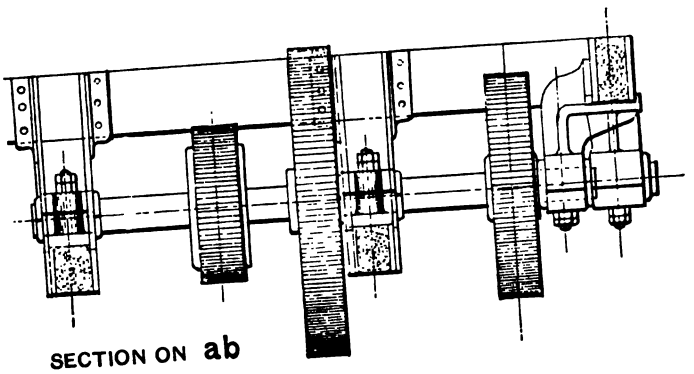


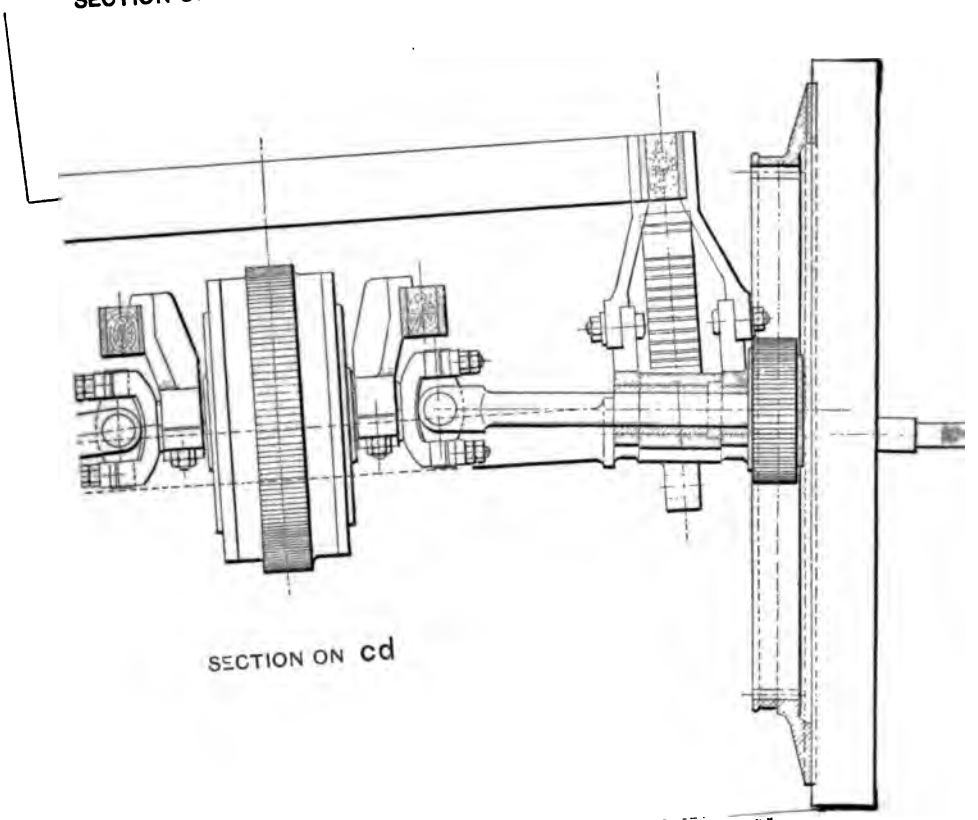
FIG. 250.

$\times\ H$ = foot-pounds, due to gravity work. FWd = friction work in foot-pounds = $WH - \frac{Wv^2}{2g}$, being work due to gravity less the



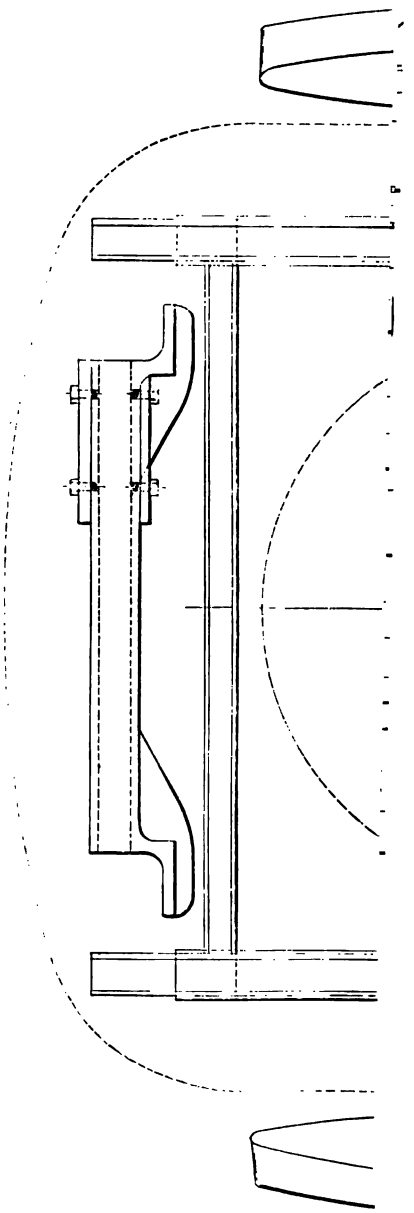


SECTION ON ab



SECTION ON cd

AMERICAN BANK NOTE CO., N.Y.



ing coils is put in each treating tank; the exhaust steam from the pumps passes into these coils, raising the temperature of the water 114 degrees Fahr.; the condensed steam passes into the clear-water well. When the plant was put up, iron pipe was used in these heating coils, but experience proves that nothing but brass or copper pipe should be used for this purpose.

Having considered all the conditions necessary for accurate and uniform treatment, and for complete chemical reaction, the next problem is the mechanical one of separating the lime sludge precipitated from the water. The amount of sludge in water-softening plants is much larger than in ordinary filtration plants, because the soluble impurities as well as the suspended matter are removed; and furthermore, the caustic lime used is also precipitated, therefore subsidence is necessary before the water can be passed to the filters. The settling tanks act as subsiding basins as soon as the stirring device is stopped and the circulation of the water ceases. It is found to be more economical in ground space and first cost to use filters for the final clarification than to use settling tanks of such size that the water will stand in them long enough to clarify perfectly by sedimentation. Furthermore, in this plant the sludge of previous precipitations is left in the tanks; this is mixed with the water of the next treatment and gathers up the new finely divided precipitate into larger flakes, which settle more rapidly, and materially hastens the clarification of the water.

To cut down the amount of sludge thrown upon the filter beds to a minimum, hinged floating outlet pipes are used, the inlet to which is held about 18 inches from the top of the water; these pipes rise and fall with the water levels; they are limited in their lowest horizontal positions by means of a counterweight and chain running over the top of the tanks. In their lowest position they clear the paddles of the stirring device, leaving about 24 inches of water always in the tank; in this water is collected the precipitated sludge. When this sludge becomes deep enough to prevent the easy rotation of the paddles, it is washed out by starting the paddles, mixing up the sludge with the water left in the tanks; in this condition it flows freely out of wash pipe to the sewer. The washing of each tank of this plant is done once a week, and it takes about twenty minutes to do this. The total waste or wash water used for this purpose is about 1.3 per cent. of the total amount purified.

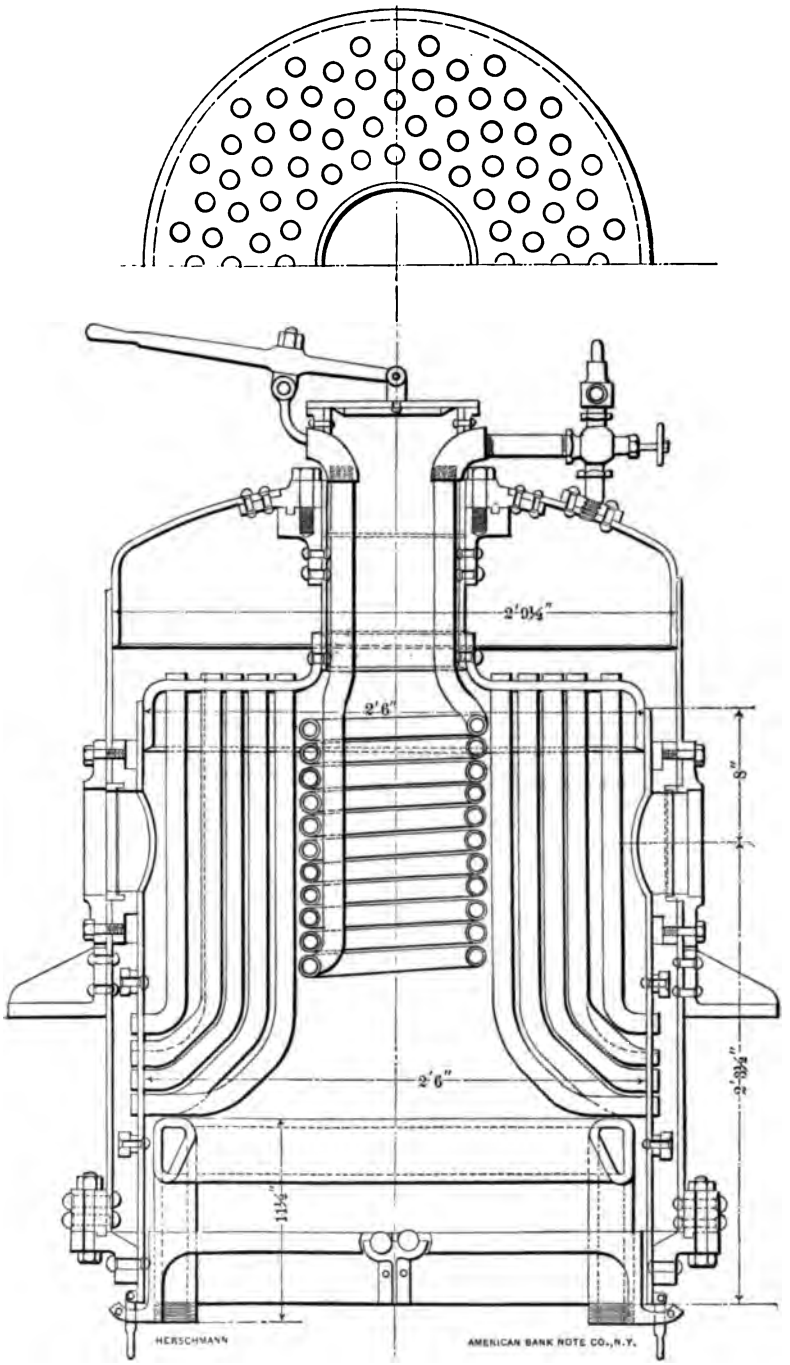


FIG. 251.

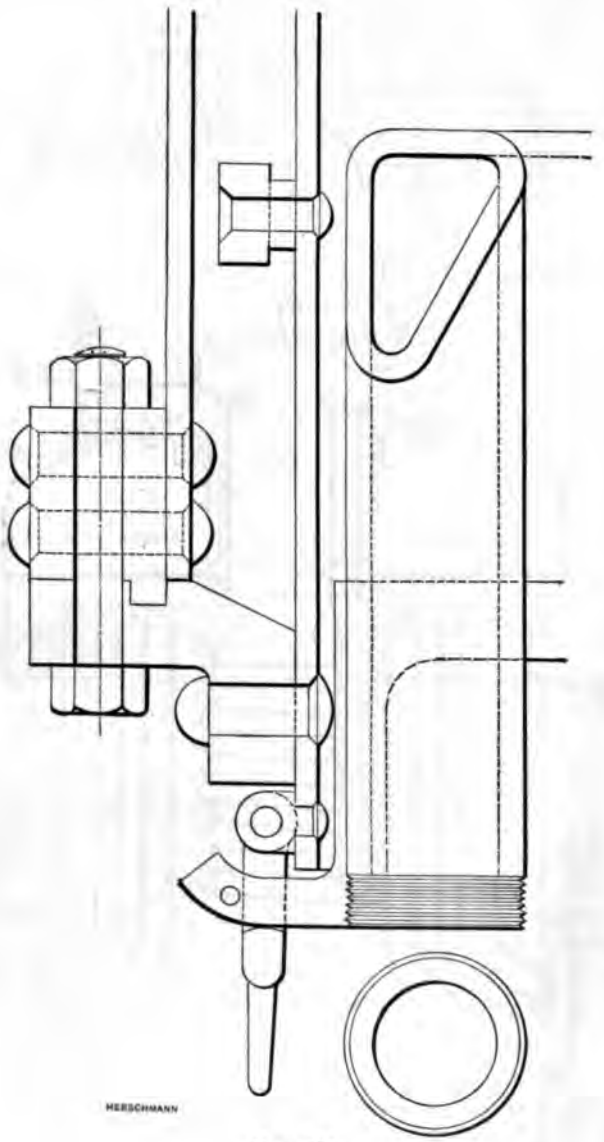


FIG. 252.

kinetic energy of the wagon in passing the point *D*. The friction is then found to be in pounds per pound of *W*.

$$F = \left(H - \frac{v^2}{2g}\right) \times \frac{1}{d}.$$

DETAILS OF BOILER, FIG. 251.

120 tubes, length 21, 22, 23¼, 25½, 28, 30 inches, average 25 inches.
Total heating surface, 81.9 square feet for 1½-inch tubes. Upper tube sheet 3.8 square feet.
Total heating surface, 73.5 square feet for 1½-inch tubes. Upper tube sheet 4 square feet.
Boiler surface, 105 square feet for 1½ inch. Superheater coil, 30 feet, 9 feet 2 inches.
Boiler surface, 96 square feet for 1½ inch. Grate area, 7.85 feet 2 inches.

DISCUSSION.

Mr. James R. Maxwell.—I think that the author does not attach the proper importance to the necessity of driving all four wheels of a motor wagon, as heavy wagons require broad steel tires, smooth enough to avoid tearing up the pavements, which will slip on greasy or wet roads and render it impossible to ascend steep hills or climb out of gutters, such as are found in most of our cities.

The necessity of driving the front and rear wheels of the wagon adds so greatly to the complications in the number and character of the parts that nearly all mechanics who are studying the subject have concluded that it is useless to try to devise a plan for doing so; but as the saying goes, "Fools will dare to tread," etc., I have given a little time to an effort to solve the problem, and offer for the consideration of the Society a sketch (Fig. 257) showing a simple method of transmitting the power from a centre shaft to the wheels, at the same time permitting the steering to be done by either the front or rear wheels or by both the front and rear wheels, in the same wagon. The scheme very much resembles that of others, and if it has any merit it is in its simplicity, using only plain, well-known elements that can be cheaply produced and that will wear a long time in hard usage. The motive power can be any of the well-known kinds now in use; my preference is to use a shaft with a worm on each end, working into worm wheels, one being right and the other left-hand, so that in regular work the thrusts will counteract each other. The motor will be arranged to drive the centre portion of the shaft, the opposite ends being driven by friction clutches, so that either the front or rear axle may be operated at pleasure.

I submit a sketch and description of my plan, showing the arrangement of one pair of wheels.

In Fig. 257 *A* is a hollow shaft having a bevel wheel on each end, the one to the right driving the wheel *X*, which drives the internal shaft *D*, which connects, through the washer, with the main wheel. *B* is the shaft that drives the other wheel, as is shown to the left. The well-known differential *E* is, of course, connected to both shafts, *A* and *B*. It will be noticed that the idler, or intermediate, wheel *X* has a good bearing and can be made very substantial.

I have studied the subject of the automobile somewhat, regarding its application to trucks for handling heavy freight, and am now satisfied that the only way to make them answer all the

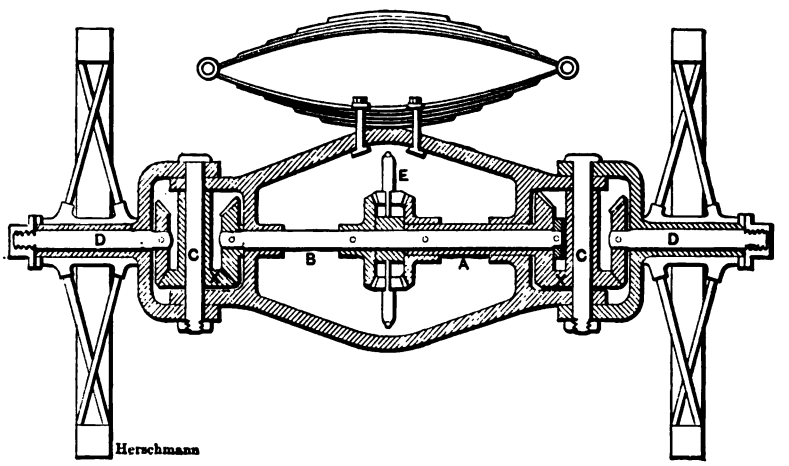


FIG. 257.

requirements is to have both the front and rear wheels driven with the same power and to also have both rear and front wheels so that the vehicle can be steered by either pair. In this arrangement the vehicle can be moved sidewise or turned around in the smallest space.

Another advantage is that the vehicle can climb out of ruts or pass over rough streets or up hills that would be impossible with a machine having only one pair of wheels driven. No more power will be required to drive an "auto" having all the wheels driven, and the gearing need not be made so strong where two sets are used.

Mr. John McGeorge.—I would like to ask Mr. Herschmann a question. On page 853 he says the tires should be smaller on

hard roads and greater on soft roads, but not on sandy roads or in snow. I could not help wondering what is his objection to the wide tires on sandy roads or in snow. This has always seemed to me as one of the crucial questions in road vehicles. We all know that on a good hard road a narrow tire will run more easily than a broad tire. But isn't it something like the man who was living on the capital, instead of on the interest, of his money? We know that we can run easier, but is it not cutting up the road? The next time he comes there, the road is not quite so good, and if they all have the narrow tires because they run so much easier, we will soon have no good roads to run on. It seems to me that we must insist, if we are to have good road service, on having wider tires than we have been using. In any case I would like to ask why he prefers the narrow tires on sandy roads or in snow.

Mr. Herschmann.—This is, of course, only a question of comparative widths. Whether for mud or snow or sand, the tires will have to be broad. But on sandy roads or snow the width is not as important, and the reason is simply this: On muddy roads the tire sinks in until it gets to ground. The mud that is above the bottom line of the wheel is not much of an obstruction. In sandy roads or in snow the wheel sinks in. But the sand or the snow above the line of traction is a very great impediment to its propulsion, and it will act like a brake; it will choke itself tight on the wheel, and will be a very great resistance to traction. Therefore if the wheel is comparatively narrow, this annoyance will not be felt to the same extent as if it is wide. Perhaps you will be able to see the reasoning of it. You always find that experiments have been made to find out whether a narrow tire or wide tire on ordinary horse-drawn vehicles is the proper thing, and if you ask the opinion of practical truckmen they will always tell you that they consider a narrow tire to be an advantage on the sandy roads or snow, for the same reason—simply because the obstruction from snow or sand is not as great as in the case of a wide tire, while in a muddy road the tire simply sinks down until it comes on the hard road itself and the mud above it is not much of an obstruction.

*Mr. William Roberts.**—I think Mr. Herschmann has overestimated the point about the gasoline vehicle, about the flexibil-

*By invitation.

ity. I will admit that in the early days of the gasoline motor carriage, speed-changing mechanisms were considered necessary—that is, the motor was run at one speed; but recent developments have proven that that is not the correct method. Motor-vehicle engines are now run at speeds varying all the way from 125 to 2,000 revolutions. In one motor vehicle which I can call to mind there is no speed-changing gear at all. The speed of the vehicle is controlled entirely by the speed of the motor. There is also in the market at present a gasoline engine which is reversible and can be reversed under full speed. But it is very fully covered with patents, and only one company, I believe, is making it. It is used very successfully. I do not think that the engine has been used in motor-carriage building, but it has been used for marine purposes.

Prof. P. M. Chamberlain.—If I understand correctly, one of the difficulties in connection with the motor carriage is the difficulty of exerting the full power of the motor at slow speeds for hill climbing, etc. With the steam engine, for instance, if the speed is reduced, the power is reduced proportionately. While not entirely original, it has occurred to me that if the oil, steam, gasoline, or any other motor can be varied within reasonable limits, and two motors were used with driving shafts running in opposite directions, connected to a differential gear, as shown in Fig. 258, when the two were running at the same speed the shaft carrying the driving wheels would stand stationary, and any variation in the speeds of the motors would cause the vehicle wheels to rotate in one direction or the other. By such a device the carriage could be driven with the full power of the motors at a very slow speed. There would be no friction clutches and comparatively little gearing, no speed-varying device, excepting as the speed of the motors is varied. I believe that this can be practically applied to the use of oil motors, and it would have the advantage, also, of allowing the motors to revolve at a low rate of speed with the carriage stationary, so long as the motors were going at exactly the same speed.

Mr. Robert Allison.—From my experience in the last two years with the gasoline motor I think that you have not got the power that you can apply in the case of emergency. Mr. Herschmann's paper speaks about the horse being able to exert extraordinary power just for a moment. On one occasion I was travelling along and I found the roads were so bad that I

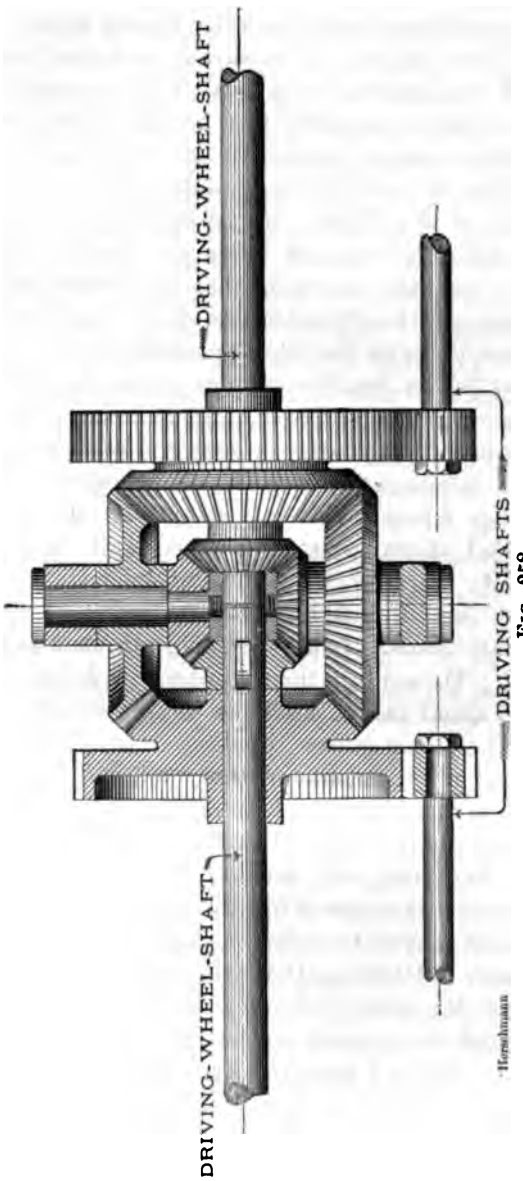


Fig. 258.

decided to turn around—I had my daughter with me—and I backed into what I supposed was a level piece of ground, but I found it was soft mud, and the rear wheels went down probably eight or ten inches. I seesawed backward and forward trying to pull out, and the more I tried to get out the deeper I got in. I could not get out of the carriage to help push it, but fortunately there was a gentleman coming along on a bicycle and I asked him if he would get off his wheel and give me a pull to get out of that ditch. By taking hold of one of the rear wheels he helped me out and I was all right. I find the difficulty in the gasoline motor is that you must have separate gears for light and heavy work, and when you put your slow gear in you are going at the rate of probably four miles an hour, and the motor is not flexible enough in its application to the machine to go up grades of five to eight per cent. on the fast gear. Then when you put on your slow gear you are going four miles an hour when you ought to be going about eight or ten. About three weeks ago I took a ride in a steam carriage with a gentleman who called at my house and asked me to take a ride with him. He said: "I would like you to take me on some pretty heavy grades," and I took him over two miles of what we consider very heavy roads. I suppose the grades run as high as sixteen per cent. He went up those grades with his steam machine at the rate of about twelve miles an hour without any difficulty whatever. The steam power appeared to be so flexible that it could meet any requirements of the road, and I was so disenchanted with my gasoline machine after taking that ride that I almost came to the conclusion that I would change from gasoline to steam. I have not fully decided yet whether I will or not. But the difference is so great in hill climbing that I thought it would be a good scheme to make the change. The steam machine appears to have a flexibility that you cannot get out of the gasoline machine. My motor will run at about 150 revolutions when there is no work being done, so that it just barely keeps going at that speed. When I want to climb a hill I find that I cannot get the power required; in fact, the motor seems to have but little power at less than 200 revolutions. I can get up a pretty steep grade if I have a clear run and can make a good start. I can get up a hill if it is not too long. But take a hill of 150 yards and it is impossible to get up without putting on the slow gear. When you get on the slow gear you come right down to about

four miles an hour instead of, as I said, running about eight or ten. The steam machine seems to me to be a more complex and difficult machine to handle than the gasoline from the fact that you have the water gauge to look after, and your steam gauge, and your gasoline that is used for fuel, and you have got to keep those things all in sight. While they are all supposed to be automatic in operation, my experience has been that you have to watch those automatic machines and see that they are working right. For that reason I think the steam machine is a little more complicated, and a little harder to handle. Although I have been in the steam-machinery business all my life, I think it is a little more difficult to handle than the gasoline machine.

Mr. Ernest F. DuBrul.—Those who have gone about this city will probably have noticed that the natural formation is one not lending itself very well to motor-vehicle use. In spite of the general mechanical development of Cincinnati, we are as yet very far behind in the matter of motor vehicles.

As regards motive power, several electric delivery wagons have been tried here, also some gasoline-driven wagons, but they have all disappeared. There were one or two electric pleasure carriages on the streets, but we see very little of them. One gasoline pleasure carriage was also bought by an enthusiast on the subject, but I understand that it is now for sale. These two motive powers have not lent themselves very readily to our topography.

Even in the matter of street railways, the hills presented great difficulties, and it was quite a while before our engineers seemed to be willing to tackle the problem of sending their cars up some of our grades. The president of the street railway company is reported to have said that even a billy goat could not get up those hills, much less an electric motor. I might add that when the prospects were that another company was willing to try the problem, the president seemed to have changed his views, for the cars are running up the grades he declared impossible, which may only prove that competition is a stronger motive power than a billy goat.

The only automobiles that have proven of any service here are steam carriages. I myself have been running one of these about town for several months. I find, as has just been indicated, that they are complicated—that they require a great deal of watching—that they are far from being perfect, and that it is a

very handy thing for a man to have his own machine shop to fall back on. Several purchasers who have not machine shops have been put to serious trouble and annoyance, but in spite of their imperfections it has been demonstrated that steam is the only practical motor for use in Cincinnati.

Steam trucks or delivery wagons, as so far designed, have not yet entered this market, not because the market is not waiting for them, but most likely because they have not as yet obtained the results that would justify their introduction here.

The delivery of goods on our hilltops is a very great problem. The heavy coal trucks, rather than pull up the hills, pay very high tolls to our inclined planes to get their loaded trucks to the top. All of this, of course, increases the cost of delivery, and the coal companies, for instance, charge twenty-five cents more per ton for delivering coal on the hilltops than in the bottoms.

If a properly designed truck, whether it be run by steam or any other motive power equally as good, would be put on our local market, there would certainly be a large sale. There is no question but that the commercial side in the way of goods delivery is the problem for engineers to work on. Pleasure carriages, automobile cabs, and other vehicles of that nature are as nothing compared with the commercial possibilities of the automobile truck.

*Mr. Herschmann.**—The criticisms or opinions which have been given by some few gentlemen here are so appropriate that I am tempted to answer them.

Referring to Mr. Maxwell's remarks about four-wheel driving, I would reply that the importance is very considerable, and the idea of Mr. Maxwell to insist on four-wheel drivers is very correct. But I would ask Mr. Maxwell to tell me how to do it. The worm gear is a surprise to me on a motor wagon. There is trouble enough on a motor wagon and waste enough without worms.

Referring to gasoline motors, a gentleman spoke about new designs and patents to come out. Granting this, I must say that at present I do not know of any such satisfactory vehicle, and I do not know of any vehicle which can run without a gear.

The idea of having two motors I did not quite grasp.

Mr. Allison's remarks I like best, because he has pointed out

---

* Author's closure, under the Rules.

water was varying very considerably, several tenths of a grain to the thousand, a gallon or more during a week.

Mr. Goldsmith.—In regard to the first part about 58 per cent. soda ash, my understanding is that 58 per cent. means 58 per cent of alkali, Na_2O, and the other 42 per cent. is the carbonic acid, CO_2. That is my understanding. I don't think I am wrong in that; I always understood it that way. The 58 per cent. soda ash is the kind we have always used, because we believe it is more economical.

Mr. Magruder.—I investigated that case only yesterday so as to be absolutely sure.

*Mr. Goldsmith.**—I am glad to get the information, and I will investigate it myself.

Now, in regard to the matter of magnesium chloride, if the reactions are as they should be, there would never be any magnesium chloride go into the boilers at all. We propose to change all the magnesium chloride by means of carbonate of soda. In other words, we use enough soda ash to precipitate the magnesia as a carbonate and form the soluble chloride of soda, which is not decomposed by heat. Therefore, we get a decomposition of the magnesium chloride. If the chemist did test for chlorine in the treated water, he would find it combined with soda, and not with magnesium. There is no method of removing hydrochloric acid from water which would be practical in any boiler equipment. Sodium salts of any kind are never removed in any water-softening plant or in any other water purifier. You cannot precipitate soda in any way. You can crystallize it by condensation. That is why it is so important that the boiler should be blown off to prevent this concentration of sodium salts as well as the concentration of any lime salts.

This plant being at a blast furnace, there is a chemist. All steel companies run laboratories, and the reason that I took the analyses from their own laboratory was simply to prove that they were probably correct, and that they were not doctored. Now a number of softening plants have been put up where no chemist is employed at all, and we simply figure first upon the water not varying to any such rapid extent as you speak of. For instance, the Ohio River water will run along for a week or ten days without change in treatment. When I spoke in the first part

* Author's closure, under the Rules.

No. 857.*

WATER-SOFTENING PLANT AT THE LORAIN STEEL COMPANY'S BLAST FURNACES.

BY N. O. GOLDSMITH, CINCINNATI, OHIO.

(Member of the Society.)

THE water supply for the works of the Lorain Steel Company is taken from the Black River.

In almost all seasons of the year it contains considerable mud and silt in suspension, and at all times soluble impurities.

Analysis of the water made in April, 1898, shows the soluble impurities as follows:

(Impurities in grains per United States gallon.)

Organic matter	1.830
Oxide of iron and aluminum	1.275
Carbonate of lime	3.244
Carbonate of magnesia	1.622
Sulphate of lime	7.455
Chloride of magnesia	1.124
Total	16.548

This water forms a scale in the boilers, which is quite hard and difficult to remove.

At the steam plants of the Shape Mill and Bessemer Department, mechanical purifiers had been used, and also tube-cleaning machines; at the same time a number of different boiler compounds had been tried, but the boilers still contained a heavy scale.

When the new blast furnace was erected, it was decided to try a more scientific method of purifying the water, and one which would remove the incrustating solids before the water reached the heaters or the boilers.

---

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Vol. XXI. of the *Transactions*.

The process known as water softening, based upon the exact quantity and chemical character of the impurities, offered the relief desired. It is a method of treating the water based upon accurate chemical knowledge, and it does not depend upon chance or the imagination of any man to prove its efficiency. A chemical process involves an expense due to the reagents used; therefore, in order to keep down the cost to a minimum, only the cheapest and most efficient reagents can be employed.

TABLE OF COST OF PRECIPITATING 1,000 GRAINS OF DIFFERENT IMPURITIES WITH DIFFERENT REAGENTS.

REAGENT.	Cost of Reagent Per Pound.	Carbonate of Lime.	Carbonate of Magnesia.	Sulphate of Lime.	Chloride. of Magnesia.
Caustic lime.....	$\frac{3}{10}$¢	.025¢	.029¢		
Soda Ash 58 per cent..	1½¢			.167¢	.243¢
Caustic Soda 74 per cent	3¢	.357¢	.407¢		
Tri-sodium Phosphate..	6¢	.942¢	1.113¢	.691¢	.997¢

The Clark process of precipitating carbonates of lime and magnesia by means of caustic lime is undoubtedly the cheapest chemical method; that, combined with soda-ash treatment for the sulphates and chlorides, makes it possible to get a clear feed water low enough in scale-forming matter to fulfil all requirements.

True water-softening is an exact process. By this is meant that the exact amount of caustic lime must be put in the water to remove all the carbonate of lime and magnesia present; and the exact amount of soda ash used to decompose all the sulphate of lime and chloride of magnesia. No more, no less.

The method of treating the water, and the apparatus used, must be so simple that a man can operate it who has no knowledge of chemistry, and of whom nothing but mechanical work is required, if it is desired to run at the lowest possible cost for operation.

If a continuous process plant is used, in which solutions of the caustic lime and of soda are made continuously, and added to a constantly moving supply of water, an exact and uniform treatment is more difficult to obtain.

First. Because the amount of caustic lime or of soda ash dissolved in a gallon of the solution may vary.

FIG. 259.—EXTERIOR VIEW, SHOWING TREATING TANKS AND BUILDING OVER FILTERS.

Second. Because the change of pressure may vary the amount of raw water supply, changing the whole character of the effluent.

Third. Because it is a difficult matter to keep uniform the amount of the chemical solutions flowing through the small orifices into the raw water.

Fourth. Because the only means of determining when the water is treated with the correct amount of caustic lime is by the depth of color given by using a chemical indicator; and no accurate means is known to determine the correct amount of soda ash used, except chemical analysis, which could not be furnished soon enough to be of any benefit.

Therefore, an intermittent settling tank plant permits more accurate and uniform treatment, and is much simpler to handle. The only question is the matter of mixing the chemicals thoroughly with the water; this is accomplished satisfactorily by stirring.

In the blast-furnace water-softening plant four open-top settling tanks are used, each 30 feet in diameter by 20 feet high; they are built of steel, and each has a net capacity of 95,000 United States gallons. Each is provided with a mechanical stirring or mixing device; this consists of two armed paddles placed at the bottom of the tank, fastened to a vertical shaft which is operated by gearing driven by a small steam engine; the paddles make about six revolutions per minute. This thoroughly mixes the chemicals with the water, and the stirring of the water always hastens the chemical reactions, as any chemist well knows.

The uniformity of treatment results from the fact that a constantly uniform quantity of water is treated in each tank, by weighing out the correct amount of the dry caustic lime and of soda ash required for each tank, and adding these to the water. To show the theoretical delicacy of this method, there is no trouble in weighing either of the dry chemicals to one-half pound (Avoir.), equal to 3,500 grains. A treating tank holds 95,000 gallons, therefore the personal error per gallon is .034 grain for each reagent used. In practice this is effected to a slight degree by the variation in the quality of the caustic lime; in the case of the soda ash, however, there is no loss. The amount of each reagent was determined when the plant was started, by chemical analysis, checked up by many analyses of the treated water. All that is necessary, then, is for the operator to add the same quantity of caustic lime and soda ash to each tank treated, until a change in

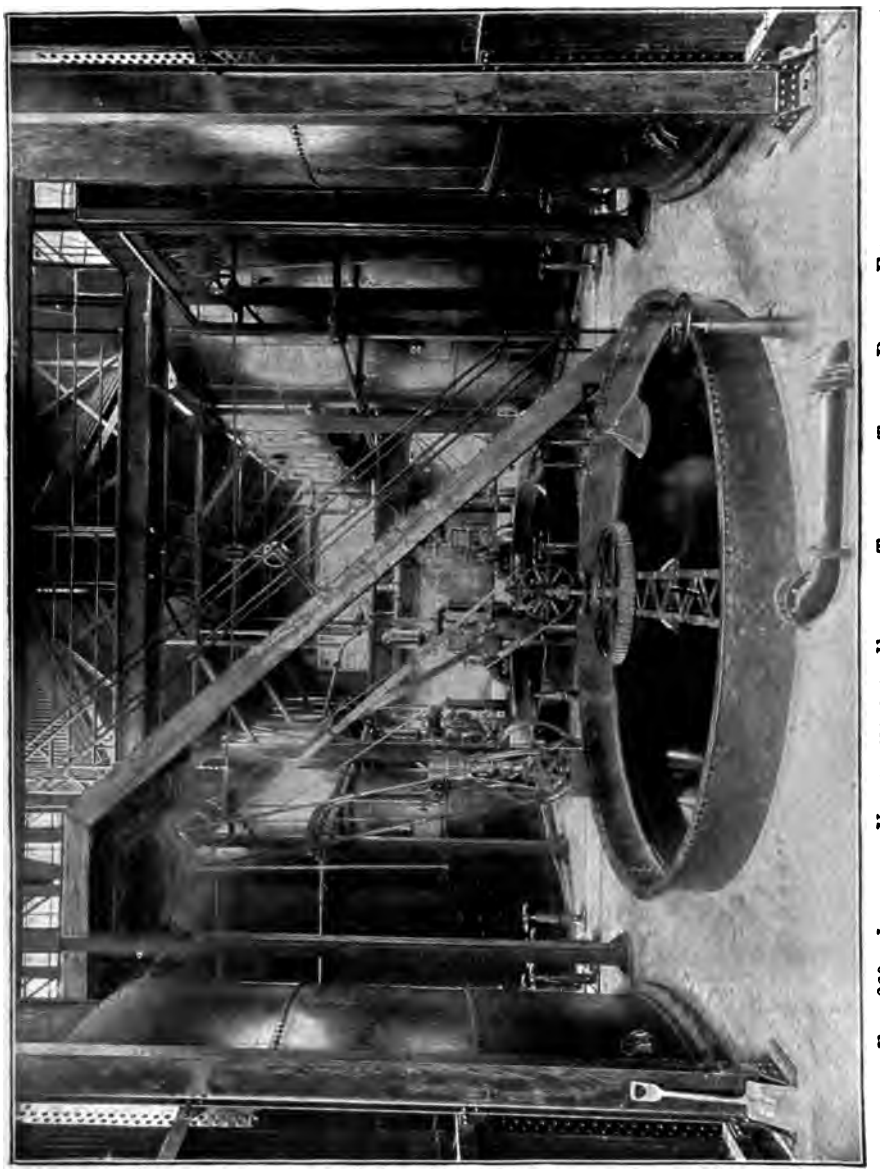


FIG. 260.—INTERIOR VIEW, SHOWING FILTERS, TREATING TANKS, PUMPS, ENGINES, ETC.

the raw water requires a change in the amounts of the reagents used.

These variations in the amounts of soluble impurities are more frequent in surface waters than in waters from deep wells, but in any case, it is not a daily, but rather a weekly or monthly one. Samples of the treated water are sent to the laboratory about once or twice a week and the water tested; any change is made only on instruction from the chemist.

To show the uniformity of the character of the treated water, the following table is given. The analyses were made in the laboratory of the Lorain Steel Company.

Date, 1899.	Raw Water: Grains per U. S. Gallon.		Softened Water: Grains per U. S. Gallon.	
	Lime (CaO).	Magnesia (MgO).	Lime (CaO).	Magnesia (MgO).
July 24	4.0	1.3	.4	.7
" 25	4.0	1.4	.5	.9
Aug. 10	3.6	1.4	.4	.7
" 17	4.1	1.6	.5	1.0
" 26	4.0	1.5	.4	1.0
Sept. 4	4.0	1.5	.4	.7
" 8	3.9	1.4	.4	.7
" 9	3.9	1.5	.6	1.3
" 11	.....	.....	.6	1.2
" 12	.....	.....	.5	1.3
" 14	.....	.....	.4	.6
" 21	4.0	1.4	.6	.8
" 22	.....	.....	.4	.5
" 25	.....	.....	.5	.8
" 29	4.0	1.5	.6	.9
Oct. 9	.....	.....	.7	.8
" 20	.....	.....	.5	.7
" 27	.....	.....	.5	.8
Averages	3.95	1.45	.5	.85

Another very important advantage of the use of treating tanks is the fact that, when properly proportioned, they allow the water to stand in them long enough to complete the chemical reactions; inasmuch as no chemical action is instantaneous, therefore time is necessary in order to get a complete precipitation and a corresponding purification of the water which is being treated. By using hot water this time is shortened. The water from the hot well of the blowing-engine condensing plant is pumped into the settling tanks; this water is from 90 degrees to 96 degrees Fahr. To further raise the temperature of the water a system of heat-

ing coils is put in each treating tank; the exhaust steam from the pumps passes into these coils, raising the temperature of the water 114 degrees Fahr.; the condensed steam passes into the clear-water well. When the plant was put up, iron pipe was used in these heating coils, but experience proves that nothing but brass or copper pipe should be used for this purpose.

Having considered all the conditions necessary for accurate and uniform treatment, and for complete chemical reaction, the next problem is the mechanical one of separating the lime sludge precipitated from the water. The amount of sludge in water-softening plants is much larger than in ordinary filtration plants, because the soluble impurities as well as the suspended matter are removed; and furthermore, the caustic lime used is also precipitated, therefore subsidence is necessary before the water can be passed to the filters. The settling tanks act as subsiding basins as soon as the stirring device is stopped and the circulation of the water ceases. It is found to be more economical in ground space and first cost to use filters for the final clarification than to use settling tanks of such size that the water will stand in them long enough to clarify perfectly by sedimentation. Furthermore, in this plant the sludge of previous precipitations is left in the tanks; this is mixed with the water of the next treatment and gathers up the new finely divided precipitate into larger flakes, which settle more rapidly, and materially hastens the clarification of the water.

To cut down the amount of sludge thrown upon the filter beds to a minimum, hinged floating outlet pipes are used, the inlet to which is held about 18 inches from the top of the water; these pipes rise and fall with the water levels; they are limited in their lowest horizontal positions by means of a counterweight and chain running over the top of the tanks. In their lowest position they clear the paddles of the stirring device, leaving about 24 inches of water always in the tank; in this water is collected the precipitated sludge. When this sludge becomes deep enough to prevent the easy rotation of the paddles, it is washed out by starting the paddles, mixing up the sludge with the water left in the tanks; in this condition it flows freely out of wash pipe to the sewer. The washing of each tank of this plant is done once a week, and it takes about twenty minutes to do this. The total waste or wash water used for this purpose is about 1.3 per cent. of the total amount purified.

From the treating tanks the water passes by gravity down the floating outlet pipe into the filters. There are two filters, each 16 feet in diameter by 7½ feet deep, having a total area of 400 square feet of filtering surface. The filter tanks are made of steel with double bottoms; in the upper bottom are placed the sand strainers, made of brass, having aluminum bronze screens and riveted with copper rivets. The upper and lower bottoms form a clear-water compartment, to which the outlet pipe is connected. The advantage of the upper bottom as a strainer diaphragm is that a uniform pressure is gotten upon all strainers when the bed is washed, and a more uniform distribution of work over the whole filter-bed is maintained while filtering; this is most difficult to get in a nest of strainer piping, due to variation of pressure in the pipe. The water flows on to the filter-bed through a central pipe, the level being kept uniform by a float controlling the regulating valve in the supply pipe. The filtering medium is crushed and graded quartz of uniform size and about three feet thick over the strainers.

The filters are provided with mechanical stirring devices, having the usual revolving rakes driven by a train of reduction gears and operated by a belt. These stirring devices are turned only when the filters are washing, by the upward current of water taken from the settling tank. It is found necessary to wash a filter once every week, and it takes about twenty minutes to wash one. It requires 20,000 gallons to wash one filter, equivalent to 1.2 per cent. of the total amount of the water purified to wash the two filter tanks. The total wash water required for the plant is about 2.5 per cent. of amount purified.

From the filters the water flows by gravity to the clear-water well, from which it is pumped by a low-lift duplex pump into the open heaters.

All piping between the settling tanks, filters, and clear-water well is set in a brick-lined pit, with a concrete floor. Only cast-iron flanged pipe and fittings are used, and flanged gate valves with outside screw-valve stems, fitted with valve-rod extensions, having cast-iron floor stands and indicators. These floor stands are placed upon floor over valve pit.

The pumps, filters and operating floor are in a cross-shaped building, constructed with a steel frame, covered with corrugated iron. The top of each settling tank is reached from the main floor by means of a stairway and bridge between the tanks. From

the platforms connected by the bridge the chemical tanks are charged by the operator, and the water is treated and tested. The plant is operated by one man for each twelve-hour shift.

In addition to the purification of the feed water before it reaches the boilers, another matter must be considered, if it is expected to keep the boilers in the best possible condition; this is the concentration of the impurities of the water, due to the evaporation and passing off of practically pure water, thereby increasing the percentage of the impurities left in the softened water. The concentration of the soluble salts, as well as those of lime and magnesia, is also important, for, although the former do not cause hard scale, because of their great solubility they do cause foaming, and even corrosion when present in the water in large amounts.

The formation of scale must be due to heat, pressure and concentration to a degree where even the more soluble salts of lime and magnesia are finally precipitated. This condition takes place only in the boilers. By using a feed water very low in lime and magnesia salts, the length of time the boilers can be run before saturation is finally reached becomes greater; therefore boilers can be run longer without washing out, and the expense of operation is decreased.

To lengthen the intervals between washing out, made necessary by concentration to a dangerous degree, it is found that regular blowing down of water from one to two gauges, depending upon the type of boiler, and pumping up fresh water is decidedly beneficial. There are twenty-two Cahall vertical boilers, 250 horsepower each, at the blast-furnace plant; in normal working condition each of these holds 292 cubic feet, equal to 2,200 United States gallons. When six inches are blown down, about 100 gallons of water are discharged; if this is done once every 12 hours, an amount equal to the entire capacity of the boiler is blown away in 11 days. The objection to blowing out hot water and pumping in cooler water is recognized as not being an economical practice, but it is one of the penalties steam users must pay when they are compelled to use water containing comparatively small amounts of soluble impurities, and want to keep their boilers free from scale. Therefore, in order to get the best condition, it is necessary to make chemical analyses, not only of the raw water and the treated water, but also of the concentrated water from the blow-off cock. This should be started when clean boilers are put in service, and samples should be taken at regular intervals, and the

concentration watched; by this means it can be determined how long it is safe to run without washing; this interval will vary with the condition of the raw water at different locations, as upon the raw water depends the character of the softened water.

If the length of time between boiler washings can be increased three or four times over what was necessary before softened water was used and regular blowing down put in practice, and if it is found unnecessary to use scrapers or tube-cleaning machines at all, because no scale accumulates or builds up; if open-exhaust steam heaters can be run from six months to one year without cleaning; if no live steam purifiers are required, and no boiler compound used, then by the use of softened water the percentage of idle capital is decreased, and the labor of cleaning boilers, heaters, purifiers, is decreased. The fuel economy is increased, first because a clean heater gives hotter feed water; second, the fuel used to heat up a cold boiler is more than that used to keep steam in a hot one. Third, a clean boiler will evaporate more water than a dirty one.

DISCUSSION.

Mr. Albert A. Cary.—This paper, describing a successful water-softening plant, is certainly very timely, as steam users in this country have within the past few years begun to rub their eyes and to wake up to the fact that scaling and corrosion in and about their boilers is not a necessary and unavoidable evil, and they are beginning to realize that an investment in properly designed water-softening appliances will yield a saving and bring them a return often equal to that obtained from their other business investments.

As I stated before this Society, in a previous discussion on this same subject, we are far behind European steam users in taking advantage of the economy possible by keeping the interior of our boilers clean and free from corrosion, but with a few installations, such as Mr. Goldsmith has described, to demonstrate the wisdom of spending money for such equipments, I believe that this country will soon lose its foreign reputation of being non-progressive in this direction.

When I first became interested in this matter of softening boiler feed waters, a number of years ago, I was connected with a concern manufacturing water-tube boilers, and the very existence of these boilers was threatened in certain sections, owing

to the impurities present in the available feed waters. My success in overcoming such troubles soon forced upon me a realization of the fact that a clean and non-corroding interior was as much of a consideration in the matter of economical steam production and the cost of maintenance as any other branch of the boiler subject, and, therefore, I have always considered this subject carefully in all boiler plants coming under my supervision, and must say that the experience thus gained has encouraged me to continue in this work.

When a new boiler plant is installed, and when more than one source of water is available, it will certainly pay in a majority of cases to investigate each water, and so determine which is the best for boiler use or the one which will yield to treatment easiest and cheapest. Good drinking water, such as supplied by the water works of towns and cities, is not necessarily a good boiler water, as some are apt to suppose. In certain cases I have found the so-called dirty waters of a neighboring stream much more preferable, as floating impurities can generally be removed by a simple sand filter. In cities such as New York, where ten cents is paid per each hundred cubic feet of city water used, or in Jersey City, where a 50 per cent. greater tax is collected, it will pay in many cases to sink wells and treat the water thus obtained, which will seldom cost for treatment a quarter of the price of city water.

There are two generally recognized methods of treating boiler water. There is the chemical method, such as described in Mr. Goldsmith's paper, depending upon the use of one or more chemical reagents, which will precipitate certain insoluble impurities formed by the reaction which takes place; and at the same time a formation of certain very soluble salts takes place, which are held in solution in the water at all boiler temperatures, and which will not precipitate unless allowed to concentrate in the boiler to an unreasonable extent. This is easily and satisfactorily avoided by blowing off at intervals.

The second method of treatment is a mechanical one, which depends upon heating feed water in a vessel before it enters the boiler, which causes the precipitation of the carbonates in the low-temperature apparatus, and the carbonates and sulphates in the high-temperature "purifier."

These precipitations are thus accomplished by taking advantage of the fact that the carbonates remain in solution principally

as bicarbonates, and the extra molecule of carbonic acid is driven off as the temperature of the solution is raised, leaving behind the almost insoluble monocarbonates, which fall to the pans or shelves prepared to receive them.

Investigation has shown that when a temperature of 180 degrees Fahr. is reached a large percentage of the bicarbonates are precipitated as insoluble monocarbonates, and at 290 degrees Fahr. (the temperature of steam under 43 pounds gauge pressure) the precipitation is almost complete. This statement is, of course, qualified by certain preëxisting conditions.

Concerning the sulphates, we are most interested in the sulphate of lime in boiler waters, as that is the most troublesome scale-former, and when the sulphate of magnesia is present it will be found quite soluble at all boiler temperatures, and, therefore, a source of very little trouble.

The solubility of sulphate of lime is shown at different temperatures, as follows:

At 32 degrees Fahr. 120 grains per United States gallon.
At 68 degrees Fahr. 141 grains per United States gallon.
At 122 degrees Fahr. 147 grains per United States gallon.
At 158 degrees Fahr. 142 grains per United States gallon.
At 212 degrees Fahr. 127 grains per United States gallon.
At 240 degrees Fahr. 10.5 grains per United States gallon.
At 250 degrees Fahr. 9 grains per United States gallon.
At from 250 degrees to 302 degrees Fahr. it is practically insoluble.

Advantage is taken in the mechanical purifiers of the fact that an increased temperature above 122 degrees Fahr. decreases the ability of the water to hold the sulphate of lime in solution, and when the feed water is thus heated a considerable percentage of this salt is precipitated, but it will be seen that a temperature much above that of exhaust steam is needed, hence the so-called live-steam purifier (using steam direct above the boiler) is required.

It is not to be expected that the results obtained will be fully equal to those shown in the above table, as absolutely perfect conditions cannot be produced in a commercial device, but it is claimed that they are more or less approximated according to existing conditions.

The precipitation is received in this case, as described before, upon pans or shelves, from whence it may be removed at intervals.

It may be said that I have not covered in these two descriptions all the methods of boiler-water remedies, as there may be those present who advocate boiler compounds and other nostrums, but I have only to say that the use of these may be warranted in comparatively few cases, but otherwise they may be compared to a man who will knowingly eat poison with his food and depend upon some antidote he has ready to protect himself from the harmful results.

As to the comparative merits of the two systems described of so-called feed-water purifications, I must say that any opinion I might express after an intimate knowledge of both would need such qualifications that the opinion would be a very obscure one. I have found that each case met with in boiler-water treatment deserves a separate consideration, the same as doctors find necessary in the treatment of disease.

I will say, however, that the chemical treatment, similar to that described by Mr. Goldsmith, is the most flexible, and there are very few waters that cannot be treated by its use, while the mechanical treatment is somewhat more limited in its application; but in some cases the mechanical treatment will be found cheaper or more applicable, and, as far as that goes, the same may be said of the chemical method of treatment in other cases.

The importance of this subject has appealed to me so strongly that I have recently gone to the expense of equipping a laboratory with a complete outfit for analyzing boiler feed waters, and afterwards treating them both mechanically and chemically, and thereby to determine the best possible method for their use.

This equipment includes a bronze boiler, which can be safely operated under 350 pounds pressure; a steam superheating device; a small mechanical purifier, constructed similarly to the boiler; evaporators, filters, and tanks for chemical treatment; and I am now carefully collecting and tabulating results obtained, with a view to preparing a paper to present to this Society.

I wish to add to Mr. Goldsmith's paper one other point of advantage which he has not mentioned:

The tanks he uses can be made most valuable measuring devices, and the amount of water evaporated in the boilers can thus be determined with a considerable degree of accuracy, and entered in a log-book alongside of the coal consumed. Thus the relative value of different kinds of coal can be practically determined and the daily consumption of steam noted.

Mr. A. Sorge, Jr.—The paper presented by Mr. Goldsmith is of considerable interest to the profession, and calls attention to the increasing tendency on the part of engineers to provide for proper treatment of the feed water before same enters the boilers. The method employed at the Lorain Steel Company is well known and has in many instances given very satisfactory results. Mr. Goldsmith states very correctly that true water softening is an exact process. However, this process is not limited necessarily to the use of caustic lime for the precipitation of the carbonates of lime and magnesia. Mr. Goldsmith's whole argument is based upon the purification of the water at a temperature not exceeding 114 degrees Fahr.; and this low temperature not only calls for the use of caustic lime, but it also involves a very extended period of time to produce the proper chemical reaction in the way of precipitation as well as for settling. As Mr. Goldsmith states, by using hot water this time is shortened. Some experiments which I have made show that when the temperature of the water is raised to 200 degrees Fahr. or over, the chemical reaction takes place very rapidly, and settling also occurs much more quickly than at the lower temperatures. Furthermore, at the temperature of 200 degrees Fahr. the soluble bicarbonates of lime and magnesia are transformed into the insoluble monocarbonates, thereby avoiding the necessity of the use of caustic lime for the sake of absorbing the extra part of carbonic acid in the bicarbonates. The addition of soda ash to water at a temperature of 200 degrees Fahr. or over gives an almost instantaneous reaction with the sulphate of lime, producing a monocarbonate of lime and the sulphate of soda. I have found by experiments that precipitation and settling at a temperature of 200 degrees Fahr. or over will take place in ten minutes and, therefore, the large capacity of tanks required for the system described by Mr. Goldsmith may be avoided with water at the high temperatures. I have installed several plants based upon this principle and with most excellent results. I use an open feed-water heater of ample capacity, fitted with a thoroughly efficient oil separator. Through this oil separator I introduce exhaust steam of sufficient amount into the heater, thus removing the oil and giving pure steam for heating the feed water. This steam is brought into direct contact with the feed water, which is broken up into drops by being passed over a series of

trays, and is thus heated to the highest possible temperature in the shortest time. The soda ash, which only is used in this process, is fed into the feed water before it strikes the trays, and by passing over these trays an absolutely thorough mixture is obtained. After the water has been thus treated and heated, it drops into the bottom of the heater. It then filters through a bed of crushed coke broken to the size of about a walnut, and then also passes through a bed of crushed quartz, after which it goes on to the pump and from there is delivered to the boiler. The solution of soda ash is made thoroughly uniform by passing some water through a tank containing this soda ash; then feeding this solution, by means of a special sight feeder, into the feed water of the heater. By making the water storage capacity of the heater sufficiently great to contain a ten minutes' water supply we get ample room for the chemical reaction and the settling to take place thoroughly. Furthermore, the addition of the condensed steam to the feed water itself adds the proportionate amount of distilled water, thus largely reducing the amount of scale-forming material. I have no difficulty in obtaining a uniform solution of soda ash or in keeping up a uniform flow of the chemical solution into the water. The water passing from the heater to the pump is tested periodically for its alkalinity by means of phenol-phthalein, and my experience is that this test gives very satisfactory results.

I disagree with Mr. Goldsmith in his statement that a continuous process plant cannot give as uniform treatment as the method described in his paper. The continuous process gives a more flexible system, which adapts itself thoroughly to the needs of the plant and which does not necessitate the use of the chemist at stated periods for determining variations in the water employed.

In installing systems of this character I am very careful to use an open heater of such type that it can be readily and quickly opened and cleaned.

Mr. F. B. Katte.—I would like to ask Mr. Goldsmith if he will tell me the total cost of a thousand gallons by his treatment, the total cost of chemicals, also the fixed charges on the plant.

Mr. Goldsmith.—When the plant was first put up, the cost of the treatment was about seven-tenths of a cent per thousand gallons. Since then—the plant has been running now about a year and a half—the price of soda ash has advanced so that it

ran up at one time to as high as a cent and an eighth a thousand gallons. The labor is about a third of a cent per thousand gallons.

Mr. Sorge speaks of the soda ash treatment. I suppose his experiments were carried on properly, but we never were able to get any such results. You take any water containing sulphate of lime and boil it for twenty minutes and add soda ash to it, and you will not get a complete precipitation. There is no question about that. You simply cannot get, in ten minutes or any such short time as that, a complete precipitation. It takes time to do it. The plan is practically the open-heater plan and soda-ash treatment. For my own part, I cannot see any difference between adding soda ash to the heater and adding it to the boiler. It practically gets it into the boiler, for the heater is usually so small that it is not possible for the precipitation to be completed there, so it must pass into the boiler and be completed in the boiler. Take a case to show that: In some waters we get it is not an unusual thing to have to treat water containing as high as fourteen grains of carbonate of lime to the gallon. It is not unusual to find a boiler plant evaporating 100,000 gallons of water in twenty-four hours, or about a 1,000 horse-power plant. That means about 1,400,000 grains of carbonate of lime in the 100,000 gallons of water. Divide that by 7,000 and you have 200 pounds. If you run six days, you have 1,200 pounds of carbonate of lime; that is, six barrels. Is the average open-exhaust heater big enough to hold six barrels? Of course no 1,000 horse-power heater ever had six barrels of lime in it, simply because they cannot get all the lime out of the water that way.

Mr. McGeorge.—I understood the question was how much per thousand treated was the first cost of the apparatus.

Mr. Goldsmith.—The plant was installed for the purpose of handling 1,200,000 gallons of water a day. They are not getting that much out of it, simply because they have not the boiler capacity to use it, and because they wanted plenty of capacity in the softening plant. They could double their boiler horse-power there and not increase the capacity of the plant. That plant was, as you may judge, an extensive one. It is not necessary to put them up as expensive as that. It cost about $30,000. But a plant of the same capacity could be put up just as well as need be for $18,000. The great argument in favor of purifying

water before it gets to the boilers is undoubtedly this—that you can run the boilers longer without cleaning them. We will imagine a case where the boilers, from the fact that the feed water is bad, require cleaning every two or three weeks. If you have a proper kind of water in the boilers, they will run two months, three months, in fact, I know of a plant which will run four months without cleaning boilers. Now, of course, under those conditions it practically means an increased boiler capacity. Where it is necessary to have a certain percentage of idle boilers always ready for cleaning, that percentage would be cut down very much, practically increasing the capacity of the boiler plant, and it will do away with all labor attending scraping tubes and using tube-boring machines. We certainly ought to be able, under those conditions, to get a more economical evaporation, and a number of advantages should attend that.

Mr. Magruder.—I note that Mr. Goldsmith used 58 per cent. soda ash, and that its cost was 1½ cents a pound. I wish to inquire what was the object in using 58 per cent. soda ash, containing 42 per cent. of lime salts and moisture, which I am informed is the balance, instead of 94 or 96 per cent. soda ash, the balance of which is moisture. The price that he gives of 1½ cents per pound for 58 per cent. soda ash makes it more expensive per pound of soda than the price quoted me yesterday of 2½ cents per pound of 94 per cent. soda ash.

On the first page the chloride of magnesium is given as 1.124, the carbonate of magnesium as 1.622. On page 6 the magnesium oxide is 1.3. I would like to inquire if the magnesium is found in the treated water as magnesium oxide, or as magnesium chloride. That is, did the chemist test the treated water from the boilers for chlorides? In many boiler waters we find it is difficult to get out the chloride of magnesium. It goes on into the boiler, even when the water containing it is purified at the usual speed, and at the temperature corresponding to the high pressure used. At this temperature it is dissociated into magnesium hydrate and hydrochloric acid, and as a practical result the boiler becomes pitted, due probably to the hydrochloric acid.

As to the variation in the raw water, if the water is practically constant the year round, I can readily see that you will not need the service of a chemist, and that almost any one might be able to care for the plant. I would like to ask Mr. Goldsmith if he would recommend this method of purification where the

water was varying very considerably, several tenths of a grain to the thousand, a gallon or more during a week.

Mr. Goldsmith.—In regard to the first part about 58 per cent. soda ash, my understanding is that 58 per cent. means 58 per cent of alkali, Na_2O, and the other 42 per cent. is the carbonic acid, CO_2. That is my understanding. I don't think I am wrong in that; I always understood it that way. The 58 per cent. soda ash is the kind we have always used, because we believe it is more economical.

Mr. Magruder.—I investigated that case only yesterday so as to be absolutely sure.

*Mr. Goldsmith.**—I am glad to get the information, and I will investigate it myself.

Now, in regard to the matter of magnesium chloride, if the reactions are as they should be, there would never be any magnesium chloride go into the boilers at all. We propose to change all the magnesium chloride by means of carbonate of soda. In other words, we use enough soda ash to precipitate the magnesia as a carbonate and form the soluble chloride of soda, which is not decomposed by heat. Therefore, we get a decomposition of the magnesium chloride. If the chemist did test for chlorine in the treated water, he would find it combined with soda, and not with magnesium. There is no method of removing hydrochloric acid from water which would be practical in any boiler equipment. Sodium salts of any kind are never removed in any water-softening plant or in any other water purifier. You cannot precipitate soda in any way. You can crystallize it by condensation. That is why it is so important that the boiler should be blown off to prevent this concentration of sodium salts as well as the concentration of any lime salts.

This plant being at a blast furnace, there is a chemist. All steel companies run laboratories, and the reason that I took the analyses from their own laboratory was simply to prove that they were probably correct, and that they were not doctored. Now a number of softening plants have been put up where no chemist is employed at all, and we simply figure first upon the water not varying to any such rapid extent as you speak of. For instance, the Ohio River water will run along for a week or ten days without change in treatment. When I spoke in the first part

* Author's closure, under the Rules.

of the paper about the true water softening, I wanted to make that term as applied especially to the Clark process of softening, because it is an exact process. I mean by that, that you cannot use an excess or insufficiency of reagents and get good results; if you use a soda compound of any kind, you can put in a little more or less, and it makes no great difference. But if you have caustic lime in excess, it does make a difference. Therefore you must have an exact treatment. The one point then is to test the water and see that you have no excess of caustic lime. That is very simple, because you can test it with an indicator which will show immediately the alkalinity due to the excess, or for an insufficiency you can test with lime water. If it is up to where it should be, there will be no further precipitation. So it is a perfectly practical thing to run the plant by men who know nothing whatever of chemistry, but simply have enough ideas to put a test of that sort in practical use and make a success of it.

No. 858.*

REHEATERS IN MULTIPLE-CYLINDER ENGINES.

BY R. H. THURSTON, ITHACA, N. Y.
(Past President of the Society.)

REHEATERS in multiple-cylinder engines have been employed by various designers and builders from a very early period in their history. Perhaps the first to use this device was John Bourne, who tells us that he employed it in 1859. In later years, Mr. Cowper, the distinguished English hydraulic engineer, employed the plan, and in this country, as early as 1869, it was adopted by the late Henry R. Worthington in his Philadelphia pumping engine and on many later engines. It was used by Mr. Corliss, and also by Mr. Leavitt (1874) on his Calumet and Hecla Mining Company engines.

The first mention of this apparatus in engineering literature, so far as the writer has observed, occurs in the little book by John Bourne, "Recent Improvements in the Steam Engine," in which are contained so many minor practical points of value in connection with this form of prime motor. He speaks of it as a "superheater," showing his precise understanding of its place and purpose, and he evidently perceives its use to be solely that of giving a better working substance in the low-pressure element of the compound engine, to which, only, he had applied it, the triple and quadruple expansion engines not having at that time come into use and not being required at the comparatively low steam pressures then in vogue. Bourne says:

"In some cases, where double-cylinder engines are employed, a superheater is introduced between the high-pressure cylinder and the low-pressure one so as to replace the heat lost by radiation and by the production of power in the high-pressure cylinder. This arrangement, introduced by me into a steamer, about 1859, was exemplified in various engines shown at the International Exhi-

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

bition in 1862, and promises to be very serviceable in cases where a small consumption of fuel is an object of paramount importance." *

Bourne thus recognized its exact function and also states clearly his understanding that the loss of heat which it is intended to counteract comes, in part, from the performance of work in the high-pressure cylinder. He very probably also understood, although he does not so state, that the superheating sought is a remedy for effects in reduction of temperature of the low-pressure cylinder by that and other methods of heat waste provocative, in that cylinder, of initial condensation. †

About 1870 H. M. S. "Briton" was fitted with compound engines of 57 and 100 inches diameter of cylinder and 33 inches stroke of piston, with intermediate reservoir and reheater of the type introduced by Mr. Cowper years before. Steam was carried at 60 pounds, and the engines developed 2,018 indicated horse-power for six hours on her trial, consuming 1.98 pounds of fuel per indicated horse-power, hour. Surface condensers and reheating contributed to this result. At reduced powers, still better figures were reported. The relative economy of the then usual classes of engines for marine purposes was reported at the time thus: ‡

RELATIVE ECONOMY OF MARINE ENGINES—RENNIE.

"Improved"	2	pounds	coal	per	indicated	horse-power,	hour.
Simple, with surface condensers.	3.5	"	"	"	"	"	"
Simple, with jet condensers	4.5	"	"	"	"	"	"
Non-condensing engines.....	6	"	"	"	"	"	"

In a discussion of a paper by Mr. Grantham "On Ocean Steam Navigation," before the British Institution of Civil Engineers, in 1869,§ Mr. Cowper stated:

"It was many years since he had introduced, with good results, the steam-jacketed reservoir between a high-pressure and a low-

* "Recent Improvements in the Steam Engine," John Bourne, p. 15; also "Reheating," John Bourne, 1859. Thurston's "Manual of the Steam Engine," vol. i., p. 888, footnote.

† This anticipation of modern ideas and practice is but one of many exemplifications of the fact that Bourne was far in advance of his time and foresaw and often applied practically nearly all the finer developments of later engineering in this field.

‡ "On Improved Compound Engines," by G. B. Rennie, Esq., March 30, 1871: Trans. Brit. Inst. N. A., 1871.

§ Minutes of Proceedings of British Inst. C. E., vol. xxix., 1869–70.

pressure engine, with the cranks at right angles. Seven years before, he had improved upon this and had made a steam-jacketed reservoir of peculiar construction. This was so arranged that the high-pressure steam, after having been expanded in the high-pressure cylinder, and thus become low-pressure steam, entered the steam-jacketed reservoir without being heated ; but the steam, on leaving the reservoir and entering the low-pressure cylinder, was heated by a peculiar arrangement of the hot steam-jacketed side of the reservoir."

One of the few trials of engines supplied with reheaters which have afforded useful data is that of Mr. Albert F. Hall, a discussion of which appears in the *Journal of the American Society of Naval Engineers*, November, 1893. Its tabulated data are here reproduced with the appended remarks. In the first of these trials the reheater was out of use, and in the third employed but one-half as much steam as in the second. It is seen that the results of its use in the third trial are identical with those of the first, within the limits of accurate observation, although a loss of 1 per cent. was indicated ; while the second trial showed a gain by the use of reheater of about 3 per cent., employing double the amount of the steam in the apparatus that was used in the final trial.

Assuming that we may rely upon the indications of these trials, notwithstanding the small differences reported, we are justified in the conclusion that unless the reheater is made effective in superheating it is best not to employ it at all, relying in such case upon separating apparatus. It is worse than useless if superheating is not insured by its employment.

TEST OF 21 × 42 × 13.5 × 40 CROSS COMPOUND AT NEWTON, MADE JUNE 9, 1892, TO DETERMINE THE VALUE OF THE REHEATER.

Duration of test	Two hours.	Two hours.	Two hours.
Total number of revolutions	4,622	4,584	4,616
Pressure of the atmosphere	14.6 lbs.	14.6 lbs.	14.6 lbs.
Press. by gauge at the throttle	116.0 "	119.25 lbs.	119.0 "
Absolute press. at the throttle	130.6 "	133.85 "	133.6 "
Absolute press. in the reheater	Not in use.	*135.71 "	*39.52 "
Total press. per sq. in. on pump	119.54 lbs.	118.08 "	113.70 "
Temp. of main feed at engine	131.27° F.	126.30° F.	125.50°F.
" " " " " boiler	127.20° F.	123.55° F.	124.00°F.
" reheater drain at engine	Not in use.	344.35° F.	263.85°F.
" " " " boiler	" " "	290.35° F.	259.85°F.
Weight of steam through cyls.	7,586 lbs.	6,832 lbs.	7,185 lbs.
Weight of steam through reheater	Not in use.	440 "	119 "
Weight of water fed to boiler	7,586 lbs.	7,272 "	7,304 "
x = dry steam per lb. of mixture	0.993 lb.	0.993 lb.	0.993 lb.
r for pressure at the throttle	869.16	867.8	867.9
q " " " " "	318.76	320.7	320.6
q_0 for main feed at the engine	98.37	94.4	93.7
q_2 for reheated drain at do	Not in use.	315.4	233.0
$(xr + q - q_0)$ heat above 32° per lb. in cylinders	1,083.5	1,088.0	1,088.7
$(xr + q - q_2)$ heat above 32° per lb. in reheater	Not in use.	867.0	949.4
Total B. T. U. used in cylinders	8,219,431	7,433,216	7,822,309.5
" " " " reheater	Not in use.	381,480	112,978.6
" " " by engine	8,219,431	7,814,696	7,935,288.1
Revs. times the pump press.	552,513.88	541,278.72	524,839.2
Ratios of do	1	0.9796	0.9499
Ratios of feed water used	1	0.9586	0.9720
Revs. × pump press. ÷ B. T. U.	0.06722	0.06926	0.06614
Ratios of do	1	1.0304	0.9839
Revs. × pump press. ÷ feed	72.8333	74.4332	71.8564
Ratios of do	1	1.0219	0.9866

* These gauges were too small for accurate readings.

REMARKS.

During the tests all of the water fed to the boiler was pumped by the main feed pump attached to the engine, this water being carefully weighed as on previous tests. The water in the boiler was at the same height at the beginning and end of tests, and was practically at this height throughout. When the reheater was in use the water of condensation was collected and weighed. Steam was supplied to the reheater by a pipe leading from the main pipe near the engine.

In this engine steam enters the top of the jacket surrounding the high-pressure steam cylinder, from which jacket it passes through Corliss valves at the top into the cylinder. The steam after being used in this cylinder escapes through valves of the same type at the bottom into a tubular reheater, the reheating steam passing through the tubes. From the reheater the steam enters the bottom of the jacket surrounding the low-pressure steam cylinder, from the top of which it enters the cylinder through Corliss valves, escaping at the bottom into a receiver containing a coil of copper pipe, through which coil the water from the main feed pump passes on its way to the boiler. From the last receiver the steam passes through a jet condenser. In the normal running of the engine the water of condensation in the reheater is pumped to the boiler by a pump attached to the engine. All the heads are jacketed with the steam entering the main jackets. All jacket water was trapped off and thrown away. The piston rods, 4 inches in diameter, pass through one head of each steam and pump cylinder. The main steam and pump cylinders are horizontal. The air pump is vertical and single acting; the feed pumps are vertical, single-acting plungers, all attached to the engine. Carefully conducted calorimetric tests show the steam at the engine to contain 0.7 per cent. moisture. All the instruments and gauges were carefully tested. A mercurial barometer was used.

ALBERT F. HALL, M.E.

The Engineering Record in its issue of April 16, 1898, publishes the results of an engine trial by Mr. Barrus, of which the following are the essential data:

TABLE NO. 1.

DIMENSIONS OF ENGINE.

Diameter of right high-pressure cylinder, inches	$14\frac{3}{32}$
" " left " " " "	$14\frac{1}{16}$
" " high-pressure rods, inches	$3\frac{1}{2}$
Stroke, high-pressure cylinders, feet	4
Clearance, high-pressure cylinders, per cent	2
Horse-power constant 1 pound mean effective pressure, 1 revolution per minute each high-pressure cylinder, horse-power	.03673
Horse-power constant 1 pound mean effective pressure, 76 revolutions per minute each high-pressure cylinder, horse-power	2.79
Diameter of right low-pressure cylinder, inches	$36\frac{5}{32}$
" " left " " " "	$36\frac{3}{32}$
" " low-pressure rods, front end, inches	$3\frac{1}{2}$
" " " " crank end, inches	$4\frac{1}{2}$
Stroke, low-pressure cylinders, feet	4
Clearance, by drawing, per cent	2.5
Horse-power constant 1 pound mean effective pressure, 1 revolution per minute each low-pressure cylinder, horse-power	.24555
Horse-power constant 1 pound mean effective pressure, 76 revolutions per minute each low-pressure cylinder, horse-power	18.66
Ratio of volumes	6.69 to 1
Heating surface in two reheaters, square feet	220
" " " feed-water heater, square feet	172

TABLE NO. 2.

DATA AND RESULT OF FEED-WATER TESTS OF PAIR OF TANDEM COMPOUND ENGINES (NO. 2 AND NO. 3 ENGINES), GROSVENOR-DALE COMPANY.

Nominal receiver pressure	5 lbs.	9 lbs.	13 lbs.	13 lbs.
Jackets	Jackets on.	Jackets on.	Jackets on.	Jackets off.
Date	Oct. 28, 1897, A.M.	Oct. 28, 1897, P.M.	Oct. 29, 1897, A.M.	Oct. 29, 1897, P.M.
1. Duration, hours	5	5.067	5.033	4.5
2. Total weight of feed water consumed, lbs.	47,945	50,632	49,295	44,221
3. Weight of water consumed per hour corrected for leakage and moisture, lbs.	9,399	9,802.5	9,604.4	9,616.9
4. Indicated horse-power developed by H. P. cylinders, I. H. P.	347.63	342.48	323.48	350.79
5. Indicated horse-power developed by L. P. cylinders, I. H. P.	371.22	398.84	415.29	374.41
6. Indicated horse-power developed by whole engine, I. H. P.	718.85	741.32	738.77	725.2
7. Average pressure in steam pipe near engine, lbs.	144.9	144.1	143.8	144.1
8. Average pressure in receivers, lbs.	4.8	8.6	12.2	12.3
9. Average vacuum in condensers, inches	26.4	25.2	25.0	24.9
10. Average revolutions per minute, revolutions.	77.45	76.65	76.86	78.89
11. Mean effective pressure H. P. cylinders, lbs.	61.12	60.82	57.29	60.53
12. Mean effective pressure L. P. cylinders, lbs.	9.76	10.6	11	9.66
13. Dry steam consumed per I. H. P. per hour, lbs.	13.08	13.22	13	13.26
14. Pressure in steam pipe, lbs.	145	144.5	145	144.5
15. Receiver pressure, lbs.	4.8	8.5	12.3	12.8

	H. P. Cyl.	L. P. Cyl.	H. P. Cyl.	L. P. Cyl.	H. P. Cyl.	L. P. Cyl.	H. P. Cyl.	L. P. Cyl.
16. Initial pressure above atmosphere, lbs.	140.2	6.4	140	9.7	139.7	13	139.9	11.7
17. Cut-off pressure above zero, lbs.	138.1	16	140.1	19.5	140	22.4	140	21.4
18. Release pressure above zero, lbs.	38.5	5.7	40.3	5	41.3	5.6	44	5.2
19. Compression pressure above zero, lbs.	35.3	4.2	37.5	4.5	42.5	4.1	42.2	4.6
20. Mean effective pressure, lbs.	62.62	10.2	60.64	10.69	57.64	11.07	60.3	9.58
21. Back pressure at mid-stroke above or below atmosphere, lbs.	+ 6.2	− 12.5	+ 10.3	− 12.5	+ 13.8	− 12.2	+ 14.1	− 12.2
22. Proportion of forward stroke completed at cut-off	.256	.357	.265	.283	.268	.236	.293	.21[illegible]
23. Proportion of forward stroke completed at release	.962	.967	.966	.973	.962	.977	.953	.9[illegible]
24. Proportion of backward stroke uncompleted at compression	.07	.06	.076	.053	.075	.064	.085	.06
25. Steam accounted for at cut-off, lbs.	8.32	10.44	8.46	9.93	8.48	10.23	9.75	8.71
26. Steam accounted for at release, lbs.	8.97	10.43	9.14	10.09	9.26	10.62	10.27	9.79
27. Proport'n of feed water accounted for at cut-off	.636	.798	.64	.751	.652	.787	.735	.65[illegible]
28. Proport'n of feed water accounted for at release	.685	.797	.69	.763	.712	.817	.775	.7[illegible]

With jackets in action the consumption of steam was divided thus: working steam in cylinders, 89 per cent., jacket steam, 11 per cent.

The editor, commenting upon this exhibit, says:

"An economy of 2 per cent. in favor of jacketing and reheating, which was the amount shown by these trials, is hardly worth considering when we take into account the extra complication and possible increase in the danger of breakage which are incident to their use. In an engine of the size noted, say 650 indicated horse-power, the consumption of coal per week of 60 hours' run is, in round numbers, 25 tons; or, for a years' run, 1,300 tons. At $4 per ton, this represents an expenditure for fuel of $5,200 per annum. A saving of 2 per cent. on this sum is $104 per year, and this is 10 per cent. of $1,040. The extra investment for the installation of jackets and reheaters, which the saving warrants, cannot, therefore, under these circumstances, be much over $1,000. It is probable that the addition of the jackets and reheaters to the engine in question required the expenditure of at least the sum just named; so that the return indicated is just barely sufficient to pay the fixed charges on the investment. There is, however, to be taken into account the heat of the jacket water, which, if returned to the boiler, produces some advantage. In the tests in question, the temperature of the feed water was raised by the admixture of the hot water from the jacket traps 25 degrees. This, in itself, represents a saving of about 2 per cent.; but on the basis of calculation above noted, it gives only about $100 saving in a year; and such an amount is hardly worth having when the complication and possible danger incident to jacket use is properly valued.

"The result obtained on this comparison is precisely similar to that shown on a similar trial, made on an engine at the Grosvenordale Mills in 1894.* In that case, with a tandem compound engine of about the same power as the one under present consideration, and of the same general proportions, but having two cylinders instead of four, the consumption of steam per indicated horse-power per hour with the jackets and reheaters in use, was 12.45 pounds. When the jackets and reheater steam were shut off, the other conditions remaining precisely the same, the consumption was 12.69 pounds per indicated horse-power per hour,

* *The Engineering Record* of November 3, 1894.

the difference being 2 per cent. This goes to show that the comparative small effect produced by the jackets and reheater is not that of an isolated case, but it is one which is borne out by repeated investigations on different engines of the same type.

"If in the recent tests we analyze the diagrams and compare one set with the jackets in use, with another set with the jackets not in use, it appears that there is a very marked difference; and that the failure of the jacket to show a greater advantage is not due by any means to inaction. The noticeable feature in the operation of the jacket is that it increases the work done by the low-pressure cylinder. In the two comparative trials referred to in the abstract of the report, namely, the tests of October 29th, forenoon and afternoon, the horse-power developed by the low-pressure cylinder with the jacket in use was 29 per cent. more than that developed by the high-pressure cylinder. When the jackets were shut off, the increase in the power developed by the low-pressure cylinder was only 7 per cent. of the power developed by the high-pressure cylinder. Furthermore, the steam accounted for by the diagrams when the jackets were in use, was much larger in the low-pressure cylinder than in the high-pressure cylinder; while, on the contrary, when the jackets were shut off, the steam accounted for was much less in the low-pressure cylinder than in the high-pressure cylinder."

Mr. Carl Sulzer, in a letter addressed to Mr. Hamilton Hill, M. A. S. M. E., and printed in the *Transactions* of the American Society of Mechanical Engineers, in 1897,* remarks:

"We have tried the heating of all jackets by direct steam, also the heating of tubular receivers, but have found no advantage in so doing." And in a letter to the writer, Sulzer Brothers say: "We do not deny that a slight gain in economy may, in certain cases, result from tubular reheaters; but this economy is, in all cases, made up by the interest on the increased cost of the whole plant."

Mr. Charles H. Manning, who has a large experience in steam-engine operation in cotton mills, and where economy of steam and fuel is important, states in a letter to the writer:

"I am a believer in the reheaters, and know that in our own vertical triple [Amoskeag Mills, Manchester, N. H.] we receive

* *Trans. A. S. M. E.*, 1897, p. 812.

much benefit from them; but we have not been able to get exact figures."

Mr. Richard Rice says: *

"As to the value of a reheater which is sufficient to superheat the steam—for instance, like the engine at the Washington Mills, where we are getting from 50 to 60 degrees of superheat—I am not ready to form an opinion based upon any scientific facts; but I believe from what I have seen that it is of value."

Mr. E. D. Leavitt, who has had large experience, says: *

"My experience with reheaters has simply proved that they are of sufficient value to warrant their use."

Mr. A. K. Mansfield writes: *

"We have been using reheaters to a considerable extent, and have recommended their use with the belief that they are of somewhat more advantage than the steam jacket, which we like to avoid in commercial engines as they add complication and expense."

Mr. Edwin Reynolds says: *

"As a matter of fact, the best results we have ever obtained have been on engines where these reheating receivers have been used; but to what extent they affected the results we are unable to say."

Mr. Charles C. Worthington writes: *

"We have made enough tests in the direction of doing away with reheating to determine positively that the more reheating we get the better the engine works . . . the stroke is the more absolutely uniform the drier we make the steam. . . . The more we do away with the disturbances of entrainment and irregular condensation the nearer we come to the ideal conditions, and superheating and reheating are in proper line for this. We find that the engine is sensitive to any attempt to reduce the pressure in the jackets or the reheater and even if only done in the low-pressure cylinder and the last reheater, and our observations seem to indicate—although they have not been made with as much care as the importance of the subject demands—that a loss of economy follows any such attempt."

The Sibley College quadruple-expansion experimental engine, of which an account has already been given in the *Trans-*

* Correspondence.

actions of the American Society of Mechanical Engineers,* is fitted with reheaters, and although operated at 500 pounds pressure and upward, and although the superheating effected is but moderate, it is supposed that a sensible amount of gain is due to their use, and that the reported efficiency of the engine, a consumption of less than ten pounds of steam, of below 11,000 B. T. U., per hour per horse-power, most extraordinary for such a little engine, comes in some degree from this construction.

The triple engine of the Massachusetts Institute of Technology, refitted with reheaters of variable effective area of reheating surface, is reported to have given the following results in preliminary trials:

With reheaters out of use and developing 88 to 90 indicated horse-power, from 15.95 to 16.03 pounds of steam per horse-power per hour passed through the engine. With 84.93 indicated horse-power and with one reheater in use, the consumption was 15.87. With 75 and 95 horse-power developed, the two reheaters being in use, 14.9 and 14.7 pounds were used. With 105 and 107 indicated horse-power developed, the consumption was 14.7 and 14.5. Cylinder jackets were not in use. Net saving, 0.08.

The triple-expansion experimental engine of the Sibley College laboratory shows very little if any advantage in the use of the reheaters in conjunction with the jackets on the cylinders, but there is an evident more or less complete substitution of the one device for the other where used alternately, and the required improvement in quality of steam to insure the exceptional efficiency of that engine noted under its most favorable conditions of operation is approximated with either arrangement. Preliminarily well-dried steam passing through a superheater is certainly an effective system of improving efficiency.

GAIN BY USE OF REHEATERS properly applied is thus considered by those builders who have experimented with them as undoubted; but its magnitude is still a matter of question and this question cannot be fully and definitely settled until direct experiment shall have afforded a direct measure and possibly revealed a law. It may, however, be probably roughly estimated from known facts bearing upon the case. It is certain that, where producing superheating, cylinder condensation in the cylinder

* "The Promise and Potency of High-pressure Steam," R. H. Thurston, *Trans. A. S. M. E.*, vol. xviii., 1896, No. DCCXVIII., p. 160.

receiving steam through them will be reduced. It is known that, with large engines, such as are commonly fitted with these adjuncts, a superheat of 80 degrees to 100 degrees Fahr. will reduce this waste to an insignificant quantity. It is indicated by reference to experiments with steam jackets that where the latent heat of steam of boiler pressure is employed in the reduction of this waste each pound of such steam so employed saves on an average considerably more than its own amount, and general experience would seem to show that, in the class of engines here studied, the net result should be expected to be a *net* saving of from one to four or five pounds of steam worked in the engine for each pound thus expended, averaging in actual reported practice probably not far from three. The first datum would show that 10 per cent. added heat in the form of superheat of originally "dry and saturated" steam saves about 20 per cent. of the total expenditure in the engine. The latter datum indicates that 10 per cent. should in this manner save 30 or 33 per cent. where cylinder condensation attains any greater magnitude than this proportion of total steam supplied. But reheaters on a compound engine can only affect the low-pressure cylinders, and alone should be expected to save perhaps one-half these proportions, probably one-half the cylinder-condensation loss, which is in such engines usually not far from 20 per cent. in compound and 15 per cent. in good triple-expansion engines. A net 10 per cent. in the one and 5 per cent. per reheater in triple and quadruple expansion engines should not be too high a preliminary estimate. Moderate superheating would presumably precede the delivery of the boiler steam to the high-pressure cylinder, and this should, with the reheaters, insure a gain of fully 20 per cent. in the compound and 12 to 15 in the other machine.* Of the total gain not far from one-third should be derived from the reheaters. Exact test only can fully determine such questions and give the engineers a sufficient basis for contracts.

Reheaters have usually been employed both as separators and drying apparatus, and as superheaters, being introduced into the steam pipe, or the steam connection between cylinders, and supplied with high-temperature steam, or with heat from the flues or smokestack in sufficient amount to give them the desired effi-

* "Theory of the Steam Jacket," R. H. Thurston, *Trans. A. S. M. E.*, June, 1894, p. 65. "Superheated Steam," R. H. Thurston, *Trans. A. S. M. E.*, May, 1896, p. 69.

ciency.* If properly arranged, complete separation will be first effected and the steam thus dried will be then raised to a temperature considerably in excess of that of the saturated steam coming into the reheater. Every good reheater is, in fact, a superheater for the next succeeding cylinder. The degree of superheat secured is usually, in the best cases, not less than 50 degrees Fahr. (28 degrees C.), and is sometimes considerably more, while more common experience indicates simply the more or less effective separation of water from the steam, and comparatively little gain except such as comes of the reduction of the quantity of moisture present at the point of cut-off. It is, however, very generally the fact that the most striking successes in the production of exceptional economy in the use of steam are exhibited by engines fitted with superheaters between cylinders, and thus securing proper and ample "reheating." Both dispositions of the reheater—taking heat from high-pressure steam and taking it from the chimney flue—are in use, and both have given good results. Choice between them will evidently be determined by the temperature af the discharged gases at the boiler, the available temperature of prime steam, and the arrangement of the engines and boilers in matters of detail. Every designer must settle this matter for himself, having in mind the conditions controlling the case in hand.

THE METHOD OF ACTION of the intermediate "reheater" in multiple engines would seem to be very simple, and the principles controlling its employment equally so. Its office is precisely that indicated by Bourne. Its effective use depends upon the efficiency with which it can perform that office. It is valuable in proportion to its effectiveness as a superheater, and as that only. In the many cases in which it has been found of no use it will be observed that its action results in no important drying or superheating, even where it does not allow steam to pass into the succeeding cylinder wet. In those instances in which it has proved itself an economical device, according to the testimony of its designers and users, it is also to be

* Superheating may be applied to the intermediate pipes or receivers of compound, triple, or quadruple expansion engines. This may be conveniently effected by means of pipes traversing the steam pipes or receivers, and exposing heating surface, the heat being supplied by live steam of higher temperature. As in steam jacketing, the operation is attended with greatest benefit when applied to the last cylinder in a series.—*Sutcliffe.*

noted that superheating in a very marked degree accompanies its action.

The reheater in a current of wet steam, where unequal to the task of drying and markedly superheating that steam, cannot be expected to prove economically useful, since both theory and repeated experiments show that—in engines in which the ratio of expansion in any single cylinder is small at least—no observable increase in efficiency is consequent upon any variation of quality of the steam supplied, when that quality does not exceed unity sufficiently to permit reduction of initial condensation by preliminary and sensible increase of temperature of the cylinder wall and one resulting in decided decrease of the internal wastes of the system. Where the area of the heating surfaces of the reheater and the quality of the steam entering it are such as to permit drying with superheating, the effect of this latter action must be balanced against the cost of the former; thus determining a net result which, if indicating a surplus of heat applicable to superheating the current of steam, will have an economic result largely in excess of the value of the energy stored, as superheat, in this excess.

The duty of the reheater may thus be reckoned as the sum of two distinct actions: the drying of wet steam and superheating of the steam thus dried. For the first, it must be competent to supply the amount of heat, per unit weight,

$$Q = xl,$$

x being the quality of the steam entering the reheater and l its latent heat per unit of weight. The area of heating surface and the temperature-head producing flow into the drying steam, as it passes into and through the reheater, must be sufficient to furnish this amount and also the quantity, per unit weight,

$$Q^1 = 0.48\ (T_2 - T_1),$$

required to insure the demanded superheat for each unit weight of steam flowing through the reheater.

Temperature head in ample measure is thus at once seen to be an essential prerequisite to the successful use of this apparatus. This means that ample section of steam pipe between the boiler and the reheater must be secured to insure full boiler pressure in the reheater, and that where, as is now coming to be not unusual, boiler pressure is carried largely in excess of steam-

chest pressure at the engines, the full temperature and pressure head thus available should be secured at the reheater. It is easy to reduce superheating, if desired, under such conditions; but it is not easy to increase it when deficient. The wider the range of this temperature head, $T_2 - T_1$, the less the area of reheating surface demanded for a stated amount of work in drying and superheating the steam. As this head is necessarily comparatively small, the area of this appurtenance to the multiple-cylinder engine, to be effective, is as necessarily comparatively large.

The area of surface in the reheater is thus proportional to work demanded, to the reciprocal of the temperature heads, and to the resistance to heat-flow through the metal walls of the reheater. It is evidently useless to adopt an area insufficient to dry, or even sufficient to simply dry, the steam passing through it: its area must be sufficient to insure some superheating, and this point attained, the heat expended will bring a return of several times its value in all ordinary cases. This gain, as already remarked, must be charged, however, with the cost of drying quite to the point of converting the wet steam entering the reheater into thoroughly dry steam.

Since the receiver cannot act as a reheater effectively, or produce any gain, apparently, unless by superheating, it is evident that all moisture should be taken out of the steam before it enters the reheater. A separator-receiver, capable of perfect drainage, between the small cylinder and the reheater is thus, in many cases, likely to prove an advantage.

The use of the reheater in an engine having two or four cylinders in series, where it receives its heat from the chimney gases, has this peculiar advantage, in addition to that of employing heat otherwise wasted but which might be utilized by the extension of the heating surface of the boiler: the heat absorbed from the passing gases may be taken out, more completely than it would otherwise be, through the series action of the receivers themselves when acting as reheaters. That taking heat from the flue, for use between the high-pressure and the intermediate cylinder, finds the available temperature-head comparatively large, and small areas of reheating surface are needed for a stated amount of work. The reheater between the low-pressure and intermediate cylinders finds a lower temperature in the flue, but its own steam has, meantime, assumed a much lower pressure and temperature than that in the first reheater, and thus the available temperature-

range for heat transfer becomes comparatively considerable. With very high steam pressures, and a correspondingly large number of cylinders in a series, this peculiarity and economic advantage of the series engine, fitted with reheaters of sufficient area of surface, becomes, it may be fairly presumed, an item to be considered. The cost of maintenance of these drying and superheating reheaters in the flue must, however, be always seriously considered.

The advantage of superheating is always the greater as the engine without that accessory is uneconomical. The larger the amount of cylinder condensation and the greater the losses, exterior and interior, the greater the effect of any given amount of superheating. The same statement will hold of the use of reheaters: the more wasteful the engine without them and the more effectively they superheat, the larger the gain by their use. As with superheaters of the common sort also, if they do not actually superheat they are useless, since the drying of the steam may then be much better effected by the use of the simple separator. All superheaters and all reheaters should be designed in anticipation of this contingency as a possibility, and all should be fitted up with ample drainage arrangements, whether effectively superheating in regular operation or not. The purpose of the steam jacket, the superheater, and the reheater is the same with all, and they all necessarily act in a similar manner: first drying the steam if wet, then giving it so much of superheat as to sensibly reduce the amount of initial condensation during the first stages of the action of the fluid in the engine. Whichever is employed, or if all are used, the use of a system of separation as a preliminary to the superheating is economically desirable, as reëvaporation of the entrained moisture is best performed in the boiler, to which the separator should send it directly and without loss of heat *en route*. A superheating reheater is the desirable accessory, and anything short of a measurable superheat is undesirable, since the work thus performed by the complicated apparatus can be better done by one less intricate and less costly in construction and maintenance.

Conclusions, probably definite, and sufficiently accurate for practical application, may be drawn from what is already known of this subject, although we are obliged to admit that direct experiment has done little to aid us in their deduction. It is tolerably certain that a reheater, wherever and however employed, can

be of little if any value in improving the thermodynamic action of the engine if it has not sufficient power to produce some superheating, and it is no less certain that a properly proportioned and placed reheater will be of comparatively small importance if supplied with wet steam, and its value will be less as the amount of the moisture in the steam entering it is the greater, up to the point at which it ceases to produce superheating of the steam entering the succeeding cylinder.

The proper construction of the reheater is thus dependent upon the following principles:

(1) A reheater should be given such area of heating surface as will insure, under the circumstances of its operation, at least moderate superheating.

(2) The reheater must, to insure proper action, be supplied with perfectly dry steam, and must usually be accompanied by a separator out of which it may take such steam, or it must itself act as a separator.

(3) To be thoroughly effective, the reheater should take steam directly from the separator, and should deliver its own charge directly into the succeeding cylinder, thus permitting no opportunity for loss of heat and production of saturation before the charge is fairly introduced into the next steam cylinder. The separator may probably often be constructed in one piece with the reheater, with advantage in this respect.

(4) Those conditions which control in the application of the superheater apply equally well to the case of the reheater. The latter is properly a superheater placed between cylinders in series; otherwise it becomes simply a separator.

(5) With properly proportioned and adjusted superheating and reheating apparatus, multiple-cylinder engines should gain quite considerable economy, and even enough, where high efficiency is demanded, to make their employment financially desirable.

DISCUSSION.

Mr. George I. Rockwood.—I have had considerable to do with reheaters and can corroborate all that Dr. Thurston has to say about the importance of drying the steam thoroughly before it reaches the reheating surface on its way to the low-pressure cylinder. The fact that the superheating surface in the receiver of the Grosvenordale engine has to both reëvaporate the condensed steam and also superheat it, will account, I think, for

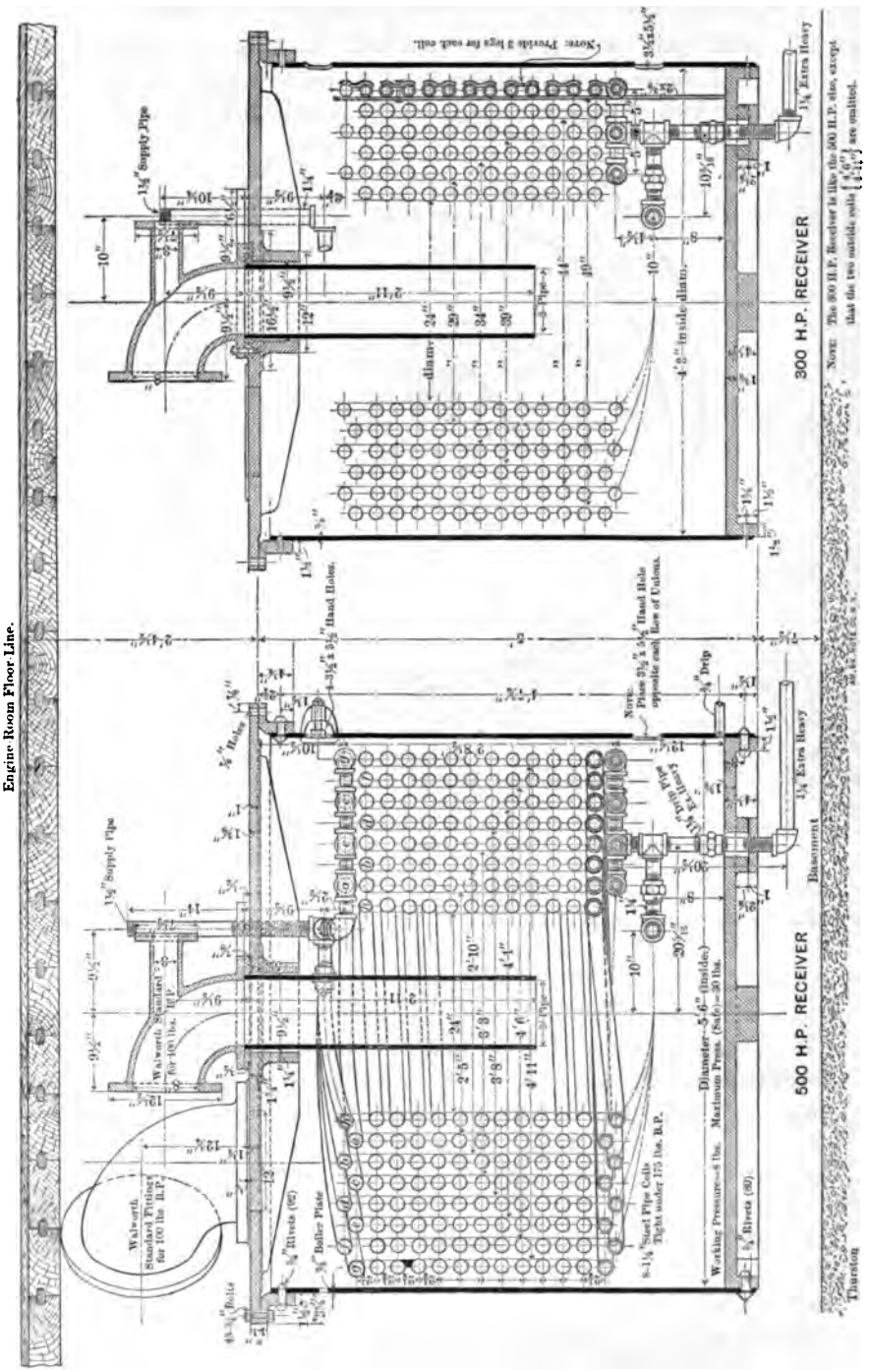

Engine Room Floor Line.
300 H.P. RECEIVER
500 H.P. RECEIVER
Basement
Thurston

FIG. 261.

the small gain of only 2 per cent. due to this reheater. The extent of surface was inadequate to do both, being one-third of a square foot of pipe surface to the indicated horse-power.

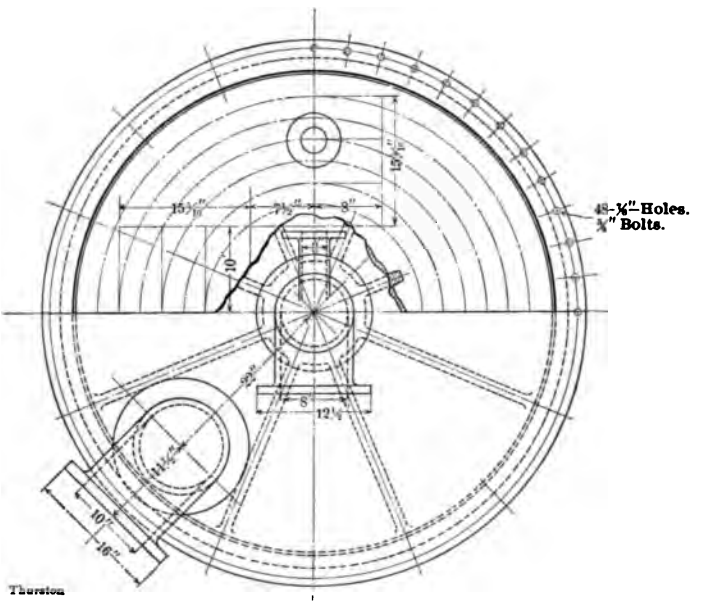


FIG. 262.

I am now having two sets of Corliss compound engines built with large cylinder ratios and large superheating receivers (Figs. 261 to 263). The amount of pipe reheating surface provided in these receivers is about one and a quarter square feet to one horse-power. The construction of the reheater is such that it acts as a separator of the entrained water and oil from the high-pressure exhaust steam before that steam comes in contact with the reheating coils. I hope that the temperature of the steam supplied to the low-pressure cylinder will be raised 60 or 70 degrees, instead of 6 or 7 degrees, as in the case of the Grosvenordale engines. The boiler pressure is to be 170 pounds and the receiver pressure 8 pounds.

The defect of almost all reheaters seems to me to be that they are merely steam driers, doing no more than a drip pipe should do. To have a superheater in use which cannot superheat does not condemn the use of such as are capable of really superheating the steam to a considerable extent.

the machine again. This sort of thing would not be safe with direct-current motors. Indeed, with direct-current motors safety appliances are furnished to cut them out of service in case of serious overload, and when this does occur it becomes necessary to go around and put them into service one by one. As already explained, this is not necessary with the induction motor.

Besides the fact that it is so simple and free from liability to accident, the induction motor requires little if any more care than a pulley. In other words, about all you have to do is to keep the bearings oiled. The induction motor possesses another advantage over almost any other piece of apparatus in the fact that the workman cannot make any adjustment which would affect its operation. There is no field current to be varied, and after the motor is brought up to speed there are no adjustments which can be made on the motor which would affect the operation of it or other apparatus on the same line.

Professor Aldrich states that a larger generating plant is required when induction motors are used than would be necessary if direct-current motors were used. With this statement I cannot agree. As the efficiency of the alternating-current generator is fully equal to that of the direct-current, and as the A. C. motors are admitted to give higher efficiencies than the D. C., it would naturally be expected that the generator should be a little smaller, if anything. The point that he has made as to the effect of induction is rather misleading. The fact is that it is necessary in the design of an alternating-current machine to so arrange it that it will allow of a larger current capacity than that due to the true work performed, but this does not necessarily mean that more true work is being done, and, obviously, if you are not doing any more true work, you do not require any more power to produce it. Indeed, the loss due to lagging currents is what electricians call a C^2R loss, and this loss will be only a very small percentage of the C^2R loss with a power factor of 100 per cent. As this latter loss is very small, it is seen at once that the loss due to lagging currents becomes practically almost negligible.

In the same way the apparent input of an induction motor may be considerably greater than the true input, especially at light loads, but this does not necessarily mean large losses at light loads. In the efficiency curves shown on page 927, the efficiency for the induction motor is better than for the direct-

No. 859.*

SYSTEMS AND EFFICIENCY OF ELECTRIC TRANSMISSION IN FACTORIES AND MILLS.

BY WILLIAM S. ALDRICH, CHAMPAIGN, ILL.

(Member of the Society.)

THE recent progress in the use of electricity for the transmission of power over short distances has developed a new industry. It bids fair to rival in magnitude and usefulness the field of long-distance transmission, much earlier developed, and now almost exclusively held by electricity. As applied to factories and mills electricity is simply a means to an end, which is primarily the transmission of power over quite short distances, from 50 to 500 feet, and within one building or a group of buildings. Upon entering this new field it has had to contest every inch of its progress in competition with long-established usage, in order to displace the unwieldy and unsightly power transmissions by shafting, belting, and rope drives. In almost all cases of new manufacturing plants, however, the features of electric transmission have received thorough consideration, resulting in many factory installations in which this system is exclusively used.

Some manufacturers have hoped that electricity would solve all of the problems, and at once, upon its introduction into their establishments; others have known it would be of no use from the beginning. There are many factories and mills in which the introduction of electricity for power transmission will not pay, under existing conditions; there are more establishments in which it would pay, in which an investment in electric transmission would prove to be a dividend-paying investment. No general rules can be laid down. Each case must be carefully examined, and a most thorough preliminary survey made of all the conditions and requirements.

In minor ways, electricity has proven to be a very useful ser-

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

vant to have around in manufacturing work, not only for lighting the establishment, but for many lines of work requiring small but easily controlled heat supply. Certain small industries have been completely revolutionized, and new lines of manufacturing work made feasible and profitable, by the use of electricity.

Each year more and more machinery is thrown into the scrap heap to make room for new and improved types, yet antiquated and costly methods of transmitting power are left in service. Modern methods of workshop production, in which machine tools are worked up to the power limit, are seen to be sought after, side by side with belted transmission of power, which makes it quite impossible to realize fully the value of the new method, by not giving the operator the utmost freedom of speed control of machine and tool. Electric-motor drives provide suitable and quickly adjusted speed ranges under all of the ordinary starting loads of workshop appliances. This has resulted in increasing the output from 10 to 80 per cent., compared with the old and fixed speed conditions with belts and gears.

Electric measuring instruments, such as ammeters or wattmeters, used in connection with the motors operating each machine or a small group of machines, have shown this method of transmission to result in a saving of from 20 to 30 per cent. of the power required by the old method. The electric motor is in operation and consuming energy only when needed. It is ready for instant service under any change of conditions of speed or power required by the work. It will meet easily 50 per cent. overload, and maintain it for half a day or till the whistle blows. It admits of readiest expansion of workshop facilities, and machines so driven may be placed anywhere to best advantage.

Electric, Steam, Compressed Air, and Hydraulic Transmission.

The system of electric transmission for a manufacturing establishment is the only one which admits of economically centralizing the so-called "mechanical plant" supplying light, heat, and power. It is a great advantage to be able to locate the power house near coal and water supplies. In some cases it thereby allows the use of condensing engines instead of non-condensing. By adopting electric transmission the engine may be located at any convenient distance from the machines, while shafting transmission imperatively requires that it be located as near at hand as possible.

If steam power is converted into electricity for all of the mechanical operations of a manufacturing establishment, it admits of a subdivision of the generating plant into duplicate and interchangeable units, the advantages of which will be apparent. The generating plant may be operated at all times in such a manner that each engine is loaded to its normal capacity. One or more units may be held in reserve for rush work and heavy orders. Night shifts can be supplied with power in units suited to their work, rather than requiring the usual single large engine to be operated as in the ordinary day shift. Nearly uniform loads may be maintained on the engines, both day and night, the electric-light load, at night, offsetting additional electric-motor service during the day.

In some cases it may be found necessary or desirable to have a mixed system of steam and electric distribution, but it can be obviated, with increased economy, by judicious installation. The use of small steam engines about an establishment, for any purpose whatever, is to be deprecated. The maximum economy to-day is to be obtained by centralized power generation.

There are, of course, certain operations in manufacturing work best performed by compressed air, while others are best performed by hydraulic pressure. Electricity does not enter these special fields. Compressed air and hydraulic pressure provide means for performing work by the more or less direct application of the energy distributed by these fluids. They would not be seriously considered as suitable systems for general power transmission for such short distances as are required in factories and mills.

For all manufacturing operations (except the very lightest) requiring rotary motion, continuous or intermittent, uniform or variable, and reversible or otherwise, electric motors provide the readiest facilities. For certain very definite reciprocating movements, with fixed time or distance limits, hydraulic mechanisms are best suited, though electric-motor-driven hydraulic mechanisms with hydraulic control have proven admirably adapted to this class of work. For reciprocating movements requiring a cushioning effect, compressed air is best adapted. But for efficient service in any case compressed air requires to be reheated and used expansively in a cylinder with all parts and mechanisms practically the same as in the steam engine. Electric transmission is equally adapted for all of the so-called auxiliary machinery of a manufacturing establishment, the non-pro-

ductive machinery, pumps, compressors, fans, blowers, cranes, hoists, lifts, etc.

The introduction of electric transmission has been greatly facilitated by the recent standardization of electrical machinery and especially that required for power purposes. This, furthermore, facilitates repairs and renewals, if it were necessary to advance this as an argument in favor of electricity. Fortunately, electric machinery as made to-day requires the simplest moving parts and the fewest repairs and renewals. Many motors have been in constant service for over six months and have required only a supply of oil. Others have been in service for years, with renewals of brushes only required.

Efficiency of Transmission at Variable Loads.

It has usually been the custom to compare the relative efficiencies of mechanical and electrical transmission without any reference to the loads, or to the proportional part of the full load on the system. It is well known that almost all examples of mechanical friction, as in steam engines, shafting, etc., show that the power lost in friction is practically constant, within all ordinary ranges of loads and at uniform speeds. This being the case, the efficiency of any mechanical system, as an engine driving shafting, rapidly falls off below full load. This is shown in Fig. 264. The engine is assumed to be about 275 horse-power, and to have a mechanical efficiency at full load of about 90 per cent. The curves for the several classes of machinery, *ABCDEF*, show similar falling off of the mechanical efficiency of power transmission by shafting. They are plotted from average values of the percentage of total power lost in such friction for shafting transmissions, as given by Prof. C. H. Benjamin in a recent paper presented to the Society.* The resulting or combined efficiency of an engine driving heavy machinery is shown in curve *M*. It is to be especially noted what little power there is left for useful work, at light loads. While at full load or 100-per cent. load there is 45 per cent. available for useful work, at three-quarters load (75 per cent.) there is only 28 per cent. available for work, and at a load of 55 per cent. of the full load there is nothing left

* *Transactions* of the American Society of Mechanical Engineers, Vol. xviii., No. 712, "Friction Horse-power in Factories," by C. H. Benjamin.

for work, all power being consumed in overcoming the combined friction of the engine and the transmission machinery.

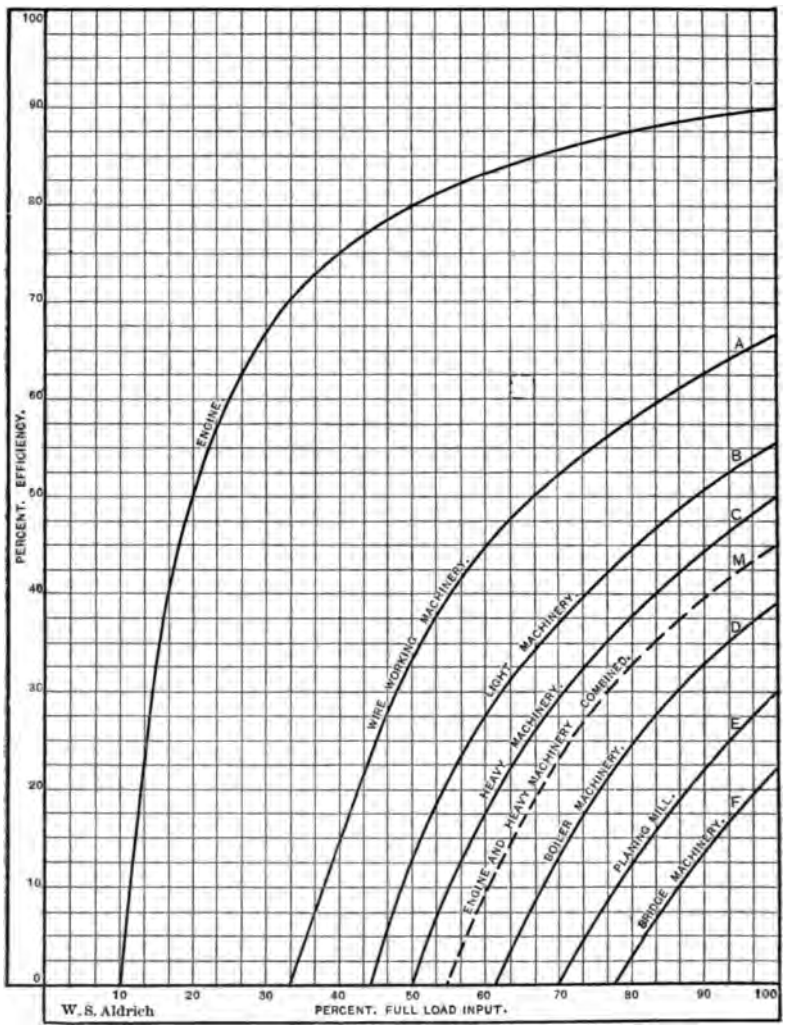


FIG. 264.—CURVES SHOWING THE VARIATIONS OF MECHANICAL EFFICIENCY OF THE ENGINE AND OF THE SHAFTING TRANSMISSION, AT VARIOUS PROPORTIONAL PARTS OF THE FULL LOAD INDICATED HORSE-POWER SUPPLIED TO THE SYSTEM.

In the electric transmission of power for similar manufacturing purposes, the distances are so short that there is really no necessity for considering any of the so-called line losses which fig-

ures so prominently in long-distance electric transmission. The transformations of energy in the electric system from steam power into electric, thence to mechanical power, are accompanied with

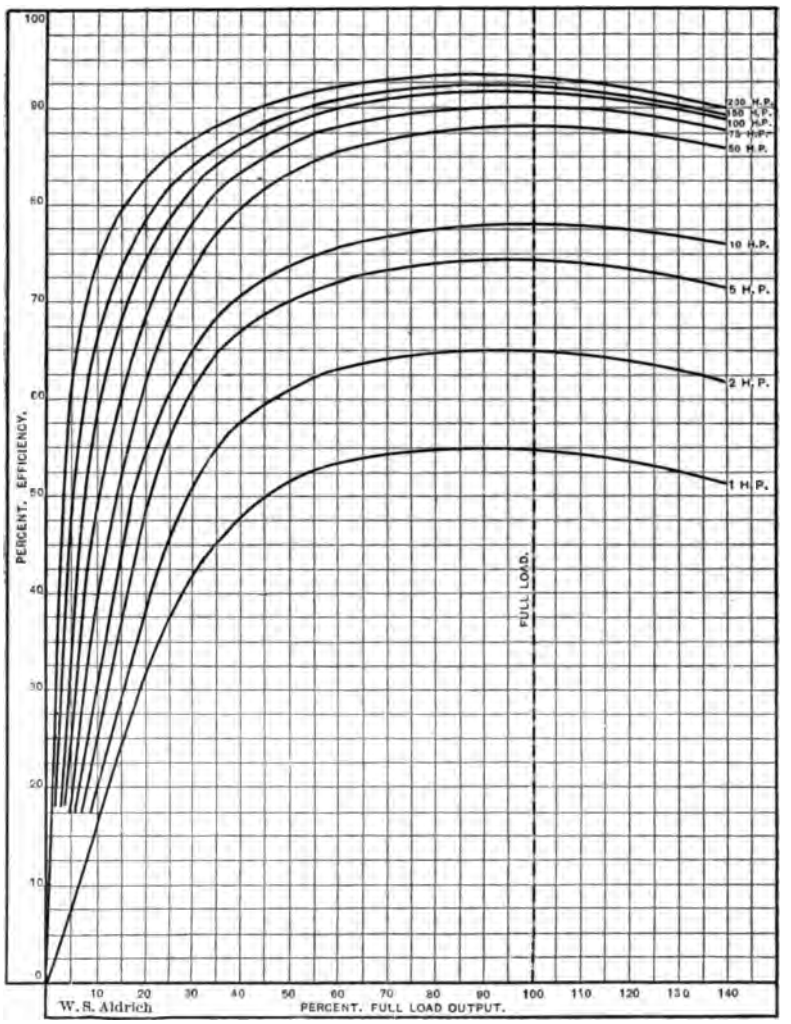


FIG. 265.—EFFICIENCY DIRECT CURRENT CURVES OF ELECTRIC MOTORS, OF THE SAME TYPE BUT OF DIFFERENT SIZES, FROM 1 TO 200 HORSE-POWER.

inherent losses, which are shown in Figs. 265 and 266. In Fig. 265 it will be noted that electric motors have the characteristic feature of high maintained efficiencies at part load. The several curves

shown are for various sizes of direct-current motors of the same type of commercial machines. Of course, such motors may be designed to have maximum efficiencies at lighter or heavier loads than those shown in the diagram.

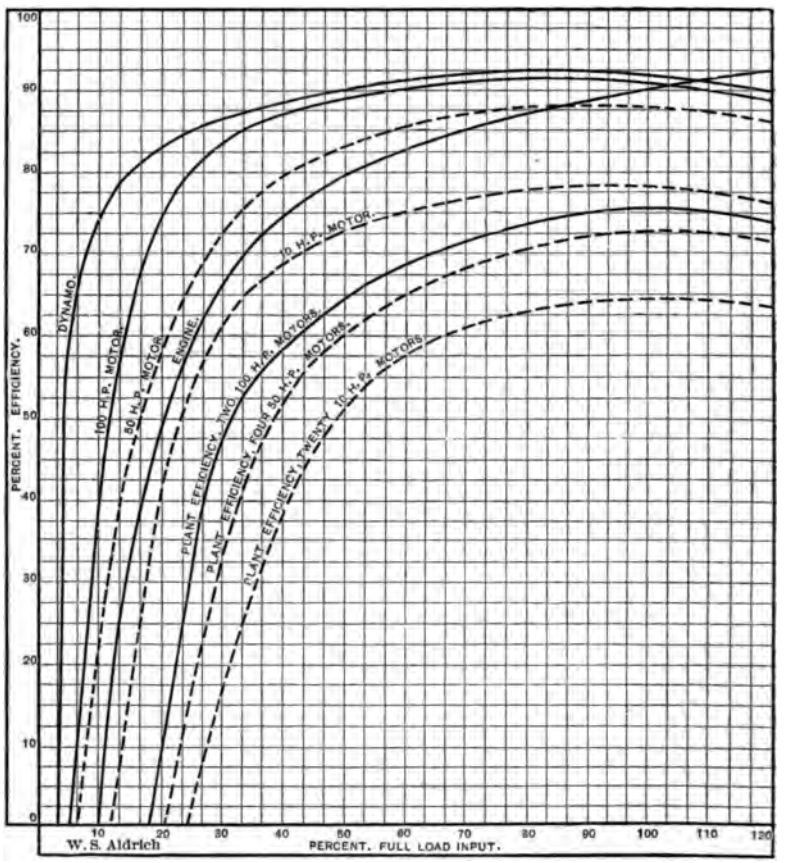


FIG. 266.—EFFICIENCY CURVES OF GIVEN ENGINE AND DYNAMO SUPPLYING POWER FOR ELECTRIC MOTORS OF DIFFERENT SIZES, WITH COMBINED EFFICIENCY OF ELECTRIC TRANSMISSION, AT VARIOUS PROPORTIONAL PARTS OF THE FULL LOAD INDICATED HORSE-POWER SUPPLIED TO THE SYSTEM.

Three cases of electric transmission are shown in Fig. 266, as follows: Two 100-horse-power motors, four 50-horse-power motors, and twenty 10-horse-power motors. The steam-engine generating plant required in each case, at normal load rating, will be of 265 indicated horse-power, 275 indicated horse-power, and

315 indicated horse-power, respectively. Some interesting features of the electric system are shown in this diagram. In what is probably an extreme case, with only small 10-horse-power motors in service, and these given quite a low rating, it will be seen that at full load (100 per cent.), 63 per cent. of the power applied at the engine is available for useful work; at three-quarter (75 per cent.) load, 62 per cent. of the power is available; at half load (50 per cent.), 51 per cent. of the power is available; while at somewhat less than one-quarter load all of the power applied is required to supply the losses in the engine, dynamo and motors. This may be compared with curve *M*, of Fig. 264, showing the combined efficiency of engine and shafting in the mechanical system. For 10-horse-power motors would, in general, represent the average (normal) rating of direct-connected electric motors for such service as that designated as "heavy machinery." In fact, the 10-horse-power motor curve of Fig. 265 is quite conservative, and in many cases such an efficiency curve might easily be brought nearer the 50-horse-power curve than the 5-horse-power curve.

It is, therefore, not so much a question of what the friction horse-power (or its per cent. of the total) may be at any load, such as the normal, as it is a question of how the total or combined efficiency of the system is going to vary with the load. The best performance of the mechanical system of transmission by shafting and belts is at full load. The best performance of the electric system may be maintained from 75 per cent. to 125 per cent. of the full load—from three-quarter load to 25 per cent. overload.

These differences become more vital when it is borne in mind that very few factories and mills are operated at full load all day. For machine-shop practice, for instance, an average of about half time for the actual work would be rather liberal. In many shops several machine tools will not be worked much more than one-third of the time. The losses at these light loads are exceedingly expensive for the mechanical system of transmission, but scarcely require consideration in the electric system. In fact, by proper selection of dynamo and motors, a combined efficiency at half load may be obtained equal to that at full load. The all-day efficiency of the electric system may thus be made very high. This is quite independent of the load factor, or the ratio of the average to the maximum load during the day. The load factors may be

the same for both the mechanical and the electric system, as shown by load curves, while in the mechanical system, for instance, at three-quarter load only 28 per cent. of the total power supplied will be available for useful work; in the electric system 62 per cent. will be so available, as may be seen by comparing curve *M*, Fig. 265, with the plant efficiency curve for twenty 10-horse-power motors, of Fig. 266.

Systems of Electric Distribution for Factories.

In choosing a system of electric transmission for manufacturing work, it is not necessarily best to have that one system which will the most readily lend itself to all of the work to be performed, for light, heat, and power service. A composite system may prove best suited, even in such short-distance transmission. That is, lighting service will, in general, be more satisfactory, and need not be more expensive, if supplied independently of the power service. Direct and alternating currents are equally adapted for factory transmission, and by simple or multi-circuit systems of distribution—that is, by two, three, or four-wire systems, as the case may require. Preferably, all distribution should be direct; that is, without the use of storage batteries, rotary converters, or transformers, except for certain lines of work in which it may be necessary to use one or the other of these indirect systems of distribution.

In the matter of voltages a wide range is possible: 110-volt two-wire and 220-volt three-wire systems for use of either direct or alternating currents for light and power; 440-volt two-phase alternating-current three or four-wire systems for both light and power; 550-volt direct-current two-wire system, or 550-volt alternating-current three-phase three-wire system, chiefly for power service, or the monocyclic system for both light and power. In general, it will not be necessary nor advisable to use over 550 volts, direct or alternating current. Shocks arising from accidental contact with wires carrying currents of this voltage are not necessarily dangerous. Experience has shown that workmen respect the distributing wires the higher the voltage. But it is not necessary to command such respect by raising it above 550 volts.

Electric Transmission by Direct Currents.

At the time that electricity was introduced into manufacturing establishments the direct-current system was the only one avail-

able. For the peculiar and exacting service required in driving all kinds of machine tools and various workshop appliances, there were difficulties to be overcome with any system. It was necessary to secure satisfactory methods of producing a large starting turning moment, or torque, for varying the speeds as might be required under uniform or variable loads, and for reducing to a minimum the trouble arising from the use of a commutator.

With direct-current motors, it was a simple matter to introduce starting boxes (resistances) in the armature circuit to control the torque, as well as rheostats (resistances) in the fields to control the speed in particular. But every such resistance meant an expenditure of energy in otherwise useless heating of the wire or other material of which these resistances might be made. The so-called Ward Leonard system came to the rescue with its two additional machines in order to operate the one given machine as a motor, at practically a constant efficiency under all conditions of load and speed. This system has been very successfully and extensively used in elevators, cranes, etc. By the use of the auxiliary machines the supply voltage may be varied according to the speed desired, and the current supplied according to the torque required, without wasting any energy in heating wasteful resistances. For conditions of factory service permitting of such an application, two motors may be advantageously used on one machine or set of machines, by means of which it is possible to vary the torque and speed quite as satisfactorily as in street-car working, by the series-parallel method of control.

The difficulties with commutators have been almost entirely overcome and many refinements in design effected, so that the direct-current motor of to-day leaves little to be desired. Such objectionable features as still remain are inherent in the direct-current system used, and are found to lie chiefly in the kind of armature, commutator, and brush devices required. These parts are most liable to derangement, require systematic attention for cleanliness and efficiency and renewals of brushes.

In heavy work, with the ordinary rough usage which an electric motor receives in a factory, a commutator may become in less than an hour so dirty as to result in considerable heating, due to increased mechanical friction of the carbon brushes, and to the increased current required by their imperfect contact. Dust-proof casings remove several of these possibilities to a more remote time. But somehow workmen expect an electric

motor to take care of itself, at least they treat it on this assumption. If a motor were sure of the daily care and inspection formerly bestowed upon shafting and belting, it would have made a much better record earlier in its history. Electric motors cannot usually be similarly inspected and attended to while at work as in the case of the older system of mechanical transmission. To have such work performed at any time requires a skilled attendant.

Electric Transmission by Alternating Currents. Induction Motors.

The alternating current system, with its induction motor service, offered practically the only alternative to those engineers and manufacturers who did not care to be troubled with the petty annoyances and delays likely to occur at any time with the direct-current motor. The induction machine as it stands to-day is probably the most perfect motor yet developed from the standpoint of electric transmission in factories and mills. It may be started and operated from any point, at any time, at practically any load and speed within its predetermined ranges. It may be used on 110, 220, 440, or 550 volt alternating-current circuits of one, two, or three phases. It does not require any direct-current supply, as the synchronous motor does for its field excitation. It does not require any brushes, commutator or collecting rings. Offsetting these advantages, however, are certain restrictions. The speed of an induction motor falls off slightly as the load is increased. This is shown in Fig. 267, in which the per cent. of such change of speed is laid off at the bottom, and is known as the slip. The ability to start an induction from rest under a heavy load, as well as the possible speed changes during its operation, are obtained at some sacrifice of efficiency.

Induction motors, moreover, permit of higher lineal speeds than are possible with any other type, from 6,000 to 7,000 feet not being infrequent. By suitable arrangements of its field windings, this type of motor may have its speed altered in regular steps, so reducing it one-half, one-quarter, one-eighth, etc. This makes possible similar changes to gear-wheel combinations, which may therefore be eliminated to the extent that the induction motor is installed to effect such changes. In almost all cases of shop driving, the slip is not objectionable, any more than the increasing slip of the driving belt as the load is thrown on.

These motors will stand almost any amount of rough usage and heavy overloads, as they cannot be burned out. If excessively overloaded, the motor slows down and stops, starting up im-

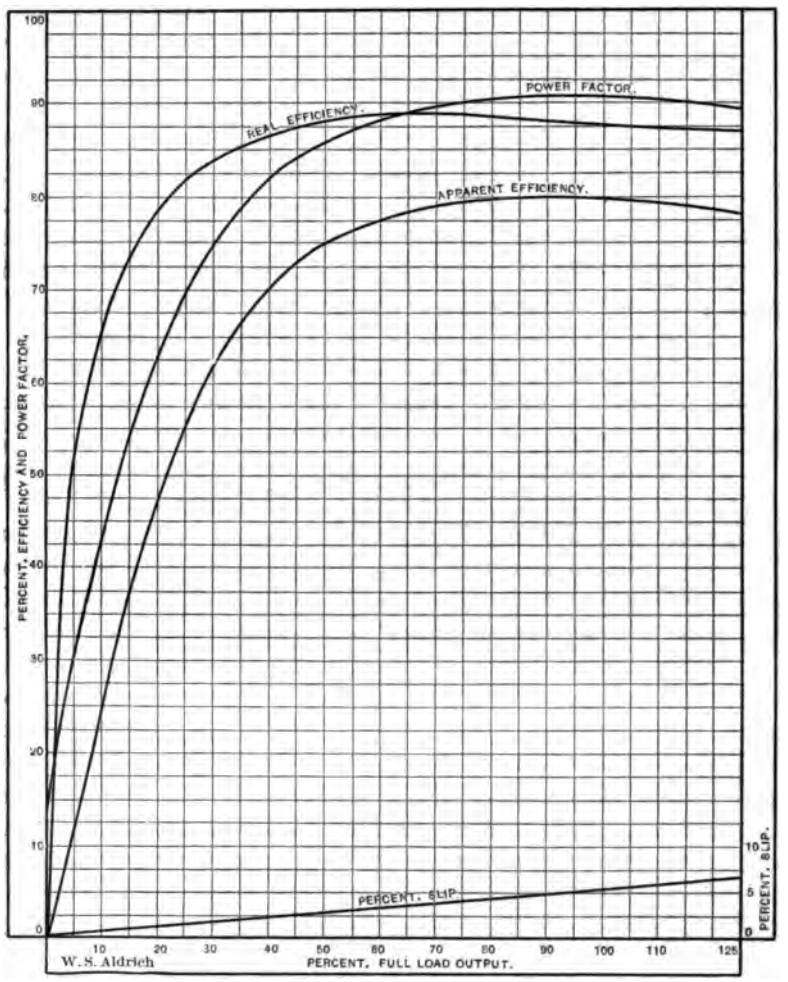


FIG. 267.—EFFICIENCY AND POWER FACTOR CURVES OF AN INDUCTION MOTOR.

mediately as soon as the load is lightened. Ordinarily, machine tools and almost all classes of shop machinery are started at quite light loads, and the full load is thrown on when the work or the tool is up to the speed desired. For this class of work the induction motor seems specially fitted.

A larger generating power plant is required for an installation of induction motors than would be the case if direct-current motors were used. This is on account of the energy which is lost in all classes of alternating current circuits in which there is considerable self-induction, whether in the transmission wires or in the appliances used. In the case of induction motors this loss is very appreciable at light loads, becoming much reduced at average and heavy loads, at which it is almost uniform. It is best represented in the form of a curve of what is known as the power factor; that is, the ratio of the true energy to the apparent energy supplied to the motor. Such a curve is shown in Fig. 267 for an induction motor of about 40 horse-power. The apparent efficiency is the ratio of the output, or delivered horse-power to the apparent energy supplied to the motor, while the true or real efficiency is the ratio of the same delivered horse-power to the true energy supplied to the motor. Curves are also shown for these values in Fig. 267 for the same motor.

Synchronous Motors.

Synchronous motors are admirably adapted to factory service where absolute uniformity of speed is required, and where the extra installation of a direct-current supply for their field excitation is not deemed objectionable. While induction motors are always wasteful of some energy, through their high self-induction, synchronous motors may on the other hand be brought into that condition of operation practically equivalent to the use of direct-current motors, at least for a large range of their loads. In other words, the power factor of a synchronous motor may be made almost anything from zero to unity, according to the extent of excitation of its fields by the direct current applied for this purpose.

When made in the revolving field type, synchronous motors are self-starting from rest, at light loads. They may be very heavily overloaded, without falling out of synchronism or out of step, and when they do for an instant, they may be brought back again by throwing off some of the load. A well-designed synchronous motor will carry at least three times its full normal load, and not drop out of step. If an induction motor is built for such overloads, it is likely to have quite low efficiency at ordinary loads.

The synchronous motor curves in Fig. 268, for a machine of about 40 horse-power, show several of the characteristics which have been previously noted. It is assumed that the motor has the same real efficiency in the two cases of different power factors, shown by their respective curves P and Q. The more nearly the power factor approaches unity, the more nearly the conditions are realized which are found in direct-current motors. The generating plant may thus be much reduced in size, compared to that required for motors with low-power factors. In fact, the power plant need not be larger than ordinarily installed for direct current working, where the synchronous motors are properly designed, installed, and operated under the best conditons.

Higher efficiencies may be obtained with synchronous motors than with induction motors of the same output. In fact, such motors realize the ideal conditions of motor working in which the motor attains almost the same efficiency as the generatory. Both induction and synchronous motors have usually higher efficiencies than direct-current motors of same size, as is shown in Fig. 269. These three curves represent the efficiencies plotted for the 40-horse-power motor in Figs. 265, 267, and 268, respectively.

Combined Induction and Synchronous Motor Working.

The ideal conditions in a factory installation no doubt would be secured where both induction and synchronous motors were used, the former for small machines and direct driving, the latter for operating a set or group of machines. The synchronous motors would be started up just before beginning the work of the day, have at all times a light constant load, and might easily be so regulated as to produce an almost balanced system in combination with the induction motors. In such a system of transmission the lagging currents of the induction motors would be offset by the leading currents of the synchronous motors, if the latter were operated to produce such leading currents. The whole system would be operated practically throughout quite a range of load variations, as if it were a simple direct-current system. The advantage of such a condition is apparent: it means least installation for any given output, or greatest output for any given capacity of generating plant.

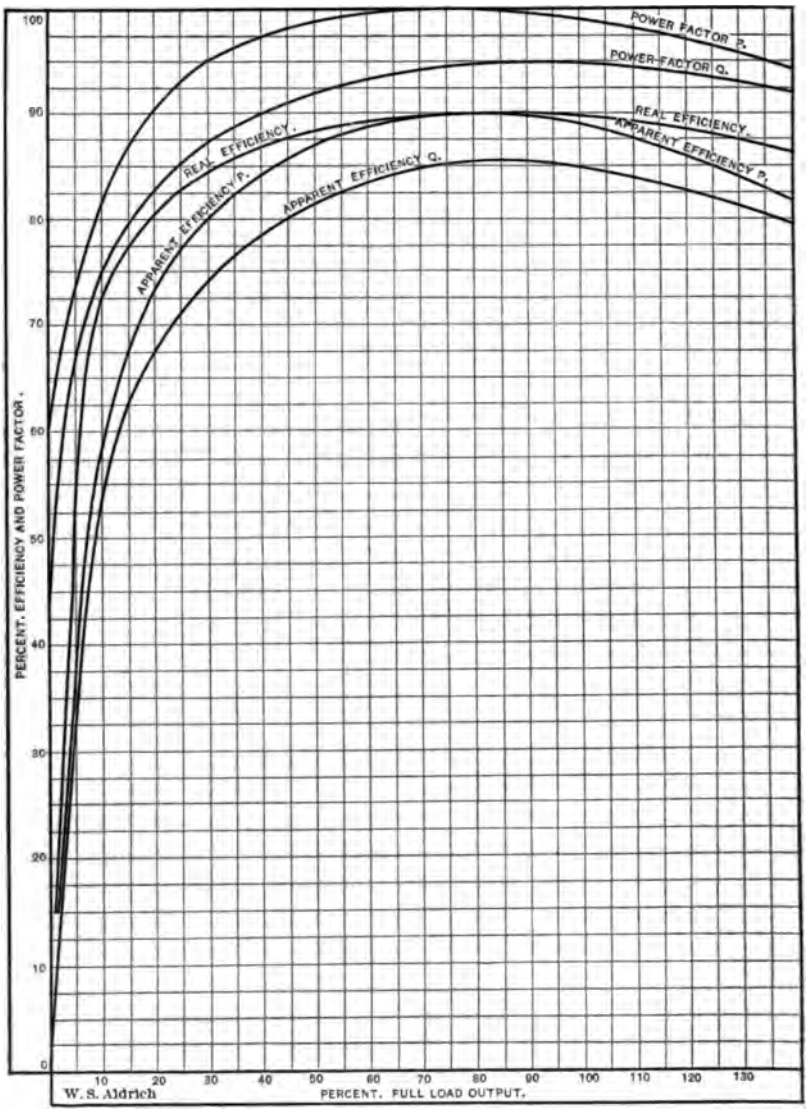


FIG. 268.—REAL OR TRUE EFFICIENCY CURVE OF A SYNCHRONOUS MOTOR FOR TWO DIFFERENT POWER FACTORS, AND APPARENT EFFICIENCIES.

The group method of electric driving might also be adopted with advantage by using synchronous motors for this service. It is much better adapted for small machines, up to and including 2-horse-power capacity, and especially where such machines are

in almost constant service. Above this size, individual motor driving, and preferably induction motors, becomes more and

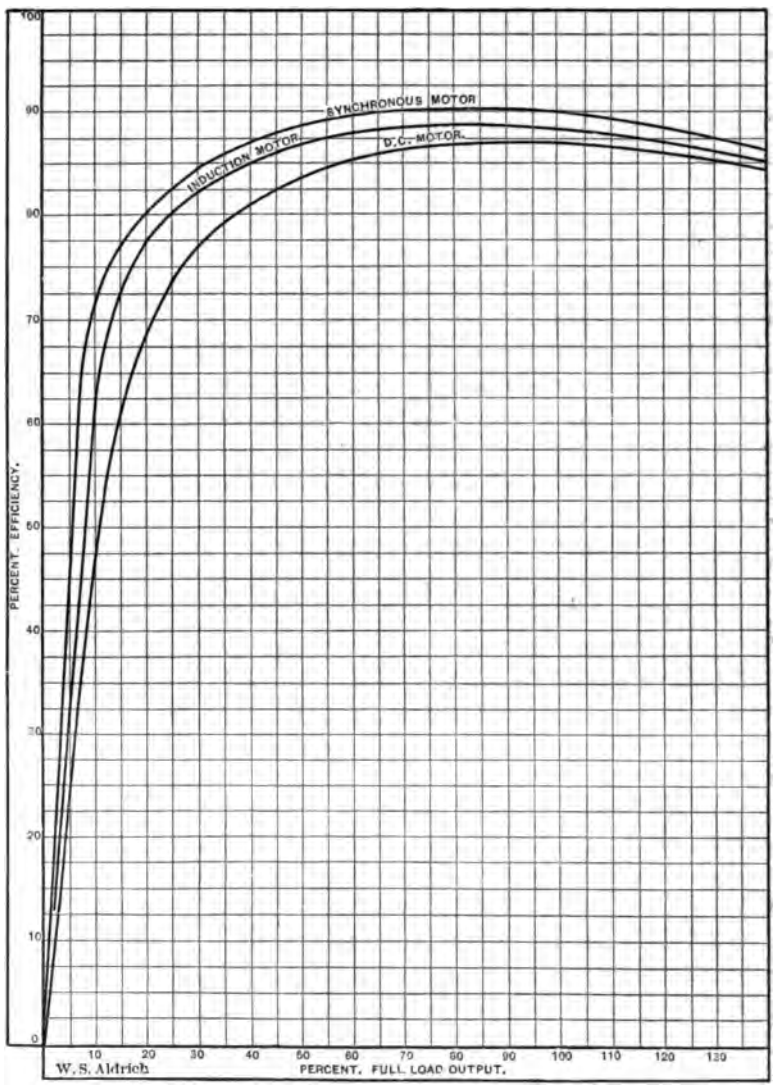


FIG. 269.—COMPARATIVE CURVES OF EFFICIENCIES OF SYNCHRONOUS, INDUCTION, AND DIRECT-CURRENT MOTORS OF THE SAME SIZE.

more efficient, particularly if the machines are operated only a fraction of the day.

Economies Effected by Electric Transmission.

It might naturally be expected that the greatest saving would be noticed in those factories designated in the earlier part of the paper as engaged in heavy machine work, where the loss in shafting and belting amounts to over 50 per cent. of the total power developed at the engine. On the other hand, many small industries have introduced electric driving to marked advantage. A few cases may be cited. No doubt many similar cases may be added by members of the Society from their own experience with electric driving.

Case I.—Electric driving reduced the cost one-half over the former method, for engineer, coal, and water.

Case II.—Fuel account, by electric driving reduced to one-fifth of what it formerly was by shafting and belting.

Case III.—Cost of power 44 per cent. lower than what it was by shafts and belts.

Case IV.—Gross saving about 30 per cent. with direct-coupled motors, and 22 per cent. with geared or belted motors.

DISCUSSION.

Mr. Walter M. McFarland.—Professor Aldrich's paper is such an excellent presentation of the subject that the remarks which I am about to make must not be taken as a criticism. They are intended rather to supplement his paper and to dwell a little more fully on some points than he has done. One point which it seems to me he has not made quite so clear as is desirable is the special advantage of the induction motor due to its extreme simplicity and almost complete immunity from accidents. The contrast in these respects between direct-current motors and induction motors is quite marked. As every one knows, direct-current motors require a considerable amount of attention to keep them in order, and it is also necessary that care should be used in stopping and starting them. With the induction motor, on the contrary, the care required is almost nil, and in many power plants where induction motors are used for machine driving, it is the custom to leave the switches closed all the time; when it is desired to stop the machines, it is done by stopping the engine driving the generator. The reverse process occurs, of course, when it is desired to start

the machine again. This sort of thing would not be safe with direct-current motors. Indeed, with direct-current motors safety appliances are furnished to cut them out of service in case of serious overload, and when this does occur it becomes necessary to go around and put them into service one by one. As already explained, this is not necessary with the induction motor.

Besides the fact that it is so simple and free from liability to accident, the induction motor requires little if any more care than a pulley. In other words, about all you have to do is to keep the bearings oiled. The induction motor possesses another advantage over almost any other piece of apparatus in the fact that the workman cannot make any adjustment which would affect its operation. There is no field current to be varied, and after the motor is brought up to speed there are no adjustments which can be made on the motor which would affect the operation of it or other apparatus on the same line.

Professor Aldrich states that a larger generating plant is required when induction motors are used than would be necessary if direct-current motors were used. With this statement I cannot agree. As the efficiency of the alternating-current generator is fully equal to that of the direct-current, and as the A. C. motors are admitted to give higher efficiencies than the D. C., it would naturally be expected that the generator should be a little smaller, if anything. The point that he has made as to the effect of induction is rather misleading. The fact is that it is necessary in the design of an alternating-current machine to so arrange it that it will allow of a larger current capacity than that due to the true work performed, but this does not necessarily mean that more true work is being done, and, obviously, if you are not doing any more true work, you do not require any more power to produce it. Indeed, the loss due to lagging currents is what electricians call a C^2R loss, and this loss will be only a very small percentage of the C^2R loss with a power factor of 100 per cent. As this latter loss is very small, it is seen at once that the loss due to lagging currents becomes practically almost negligible.

In the same way the apparent input of an induction motor may be considerably greater than the true input, especially at light loads, but this does not necessarily mean large losses at light loads. In the efficiency curves shown on page 927, the efficiency for the induction motor is better than for the direct-

current motor, even at very light loads; in consequence, if the efficiency is better, the losses must be less. The alternating-current motor at light load undoubtedly takes more current from the line than is required by the direct-current motor, but this larger current does not mean a larger consumption of power, for in each alternation of the current, part of the time the motor receives energy and the remainder of the time gives back energy to the line. A wattmeter will measure the difference between these, thus giving the true energy taken by the motor. An ammeter will measure the current taken, without regard to whether it is fed into the motor or returned, and consequently the current measured is not an indication of the energy taken by the motor. The case is similar to that of a pipe in which a meter measures the amount of fluid passing through the pipe without regard to the direction of the flow. An equal amount of fluid might pass first in one direction and then in the opposite direction, and the meter would measure the double amount, yet the amount of fluid actually delivered from the pipe would be zero.

As you will see, these remarks are amplification of what Professor Aldrich has already said, and I trust to be understood as showing a high appreciation of his paper.

On page 924 of the Professor's paper, where he speaks of synchronous motors, I must again differ from him, as conversation with our electrical experts has shown that they do not agree entirely with the views he has expressed as to the field of usefulness of the synchronous motor. As you are all aware, the synchronous motor is practically the same as an alternating-current generator, and thus requires direct current for its field excitation. There are several practical objections to the use of synchronous motors, unless in a place where they would be under the care of a good, competent, and intelligent man. As already stated, the induction motor cannot be affected by the workman. Just the opposite is true of the synchronous motor, on account of the fact that the excitation of its field may be varied. Experience has shown that, if little attention is paid to the accurate adjustment of the field excitation, the power factor of synchronous motors is usually very nearly the same as that of induction motors, while with very bad field adjustments it can be made much lower than that of the induction motor.

Another statement about the synchronous motor in the paper

is, that if it is overloaded and gets out of step, a slight reduction of the load will cause it to get in step again. Doubtless this would be true if men could be found quick enough to make the adjustment, but experience has shown that such men are rare, if, indeed, they can be found at all.

An additional advantage possessed by the induction motor is its safety, due to the absence of a commutator, so that there is absolutely no chance of sparking. This makes the induction motor especially fitted for use in any locality where sparks would be dangerous. In line with this advantage is the fact that the starting appliances for induction motors do not need to be near the motor itself, but may be placed in a convenient position. As a result of this the motor, which needs practically no attention, can be put wherever desired, while its starting device can be placed in the convenient location. This, of course, is not true of a direct-current motor, which must be kept in an accessible position on account of the attention which it needs.

As already stated, the paper is an excellent one, and I believe will prove very interesting and instructive to all the members of the Society. I felt, however, that when the opportunity for discussion offered it was best that the little points which had not been fully developed should be brought out.

Mr. John McGeorge.—There is a saying, "Save me from my friends." We have heard a great deal of the simplicity of the induction motor. If you apply it to one class of service it is simple, as it only requires three wires and a starting switch. But in cases where I have used it, it requires a great deal more than that. I applied it to crane work, and there we get into a good many complications. For instance, the ordinary direct-current motor takes four wires from the controller to the motor to enable all its operations to be performed.

Now compare that to a case which I have installed with three motors. Those three motors would take from the controllers to the motors seven wires. Now, as a fact, for the three induction motors I had to put in three wires to the auto-converters; from each of the auto-converters eighteen wires, each of these eighteen split into three to the controllers, making 104 wires; then from the controllers to the motors themselves another seven wires. Now you see what has to be provided in the cage. I believe thoroughly in the induction motor, but I think it is a little unwise to keep pressing this question of simplicity. The

motor itself is simple when you apply it to a particular class of work; that is, the direct drive of any other class of machinery. But don't do that generally, or you will at once condemn the induction motor.

Mr. Edward J. Willis.—The induction motor has now the ears of the public on account of its marvellous simplicity, it being almost ideal. It is in fact a rotating shaft without contact except its two bearings. It is almost impossible to conceive of anything simpler from a mechanical standpoint. The direct-current machine has stood the brunt of the battle of introduction, and its troubles and difficulties are well known and generally exaggerated on account of the fact that the machines themselves have been frequently badly designed, also frequently installed for work and in places to which it was not suited. A properly installed and properly loaded direct-current motor is a very satisfactory machine, and it lends itself most admirably to starting, stopping, and the changes of speed needful in shop work. If the gentlemen here will take the trouble to go out to the Bullock Electric Company, who have kindly extended invitations to us, they will see a model installation in the way of direct-current motors. It is very doubtful in my mind if any plant equipped with induction motors has the facility for changes of speed, the efficiency from the main generator, or as little repairs or maintenance as has been the experience of this installation.

It would be in keeping for me to add that I am not connected either directly or indirectly with the Bullock Electric Company, and that I call the members' attention to the installation only with the hope that they will not miss the opportunity of seeing so interesting a sample of electric driving!

Mr. Wesley.—Mr. Willis has spoken of the transmission at the works of the Bullock Company, and it has occurred to me that those who have visited the plant, or who may propose to do so, may be interested to know of the actual consumption of power in a works of this size.

At the end of the first year the wattmeter showed that the load on the generators averaged forty-two kilowatts for the whole time, being fifty-six horse-power required to drive the whole plant. Those members who have seen the plant may form from this some idea as to the efficiency of electric transmission as compared with the ordinary belting transmission. I think in a shop of that size there would be few who could show

much less than that, for driving the line shafting and belt without doing any work. Besides this work there has been the regular work of the testing of motors and dynamos sent out at the same time.

Prof. C. H. Benjamin.—It seems to me that Professor Aldrich, in his paper, puts shafting transmission rather at a disadvantage.

The examples which he quotes from my paper as a basis for his calculations are most of them examples of how not to do it, the faults being rather in the wrong construction and wrong use of shafting than in the shafting principle itself. To emphasize this, I would call attention to shop No. 13 in my paper above referred to. The total horse-power in this case was 117, and the power to drive shafting only seventeen, or 14½ per cent., including engine friction. I think my friend Mr. Webber will bear me out in saying that in New England cotton mills 15 per cent. loss is a usual figure.

Secondly, the calculated efficiency of a generator or motor, and the actual efficiency in use, are sometimes quite unlike.

I would refer to an article in *Cassier's Magazine* for January, 1900, page 220, where are given some results of electrical tests at the Baldwin Locomotive Works and elsewhere. An examination of these figures shows that the power consumed by an independent motor and its counter shaft varies from 25 to 44 per cent. of the total power used.

An average of sixteen tests on independently driven machine tools of large capacity shows 8.55 horse-power for the machine and work, and 2.35 horse-power for the motor and its counter shaft, or nearly 25 per cent. loss at this point alone.

I am an ardent advocate of electric transmission, but I think it is a mistake to make saving of power the principal argument, for I believe there are other and better reasons for its introduction.

Mr. D. C. Woodward.—Mr. Aldrich has presented a very interesting and instructive paper, and I fully agree with the general conclusion reached, that electric transmission in factories and mills is the most economical and best method.

Perhaps, however, some wrong impressions may be received by those unfamiliar with the subject, in studying his diagrams and by some of his statements.

In Fig. 266 the curves showing the plant efficiency for two 100-horse-power motors, as compared to twenty 10-horse-power motors, would lead some to believe that group-driving with

large motors is more efficient than having each machine, properly designed, driven by its own motor, but it is a mistake to think so.

The poor economy of shafting and belts is shown in Fig. 266. In giving the plant efficiency, using two 100-horse-power motors, the loss of power in shafting and belts, which must have been used, should be included. This would bring the efficiency lower than that for twenty 10-horse-power motors.

In constructing his curve for plant efficiency for twenty 10-horse-power motors, if I mistake not, he has assumed that all of the twenty motors are doing the same amount of work at the same instant, which is an improbable case.

To illustrate a condition more to be expected in a shop with motors on all the heavy machines, I have calculated the efficiency of a plant of about 300 horse-power with an engine, dynamo, and fifty motors, forty of 5 horse-power and ten of 10 horse-power each.

As the efficiency curve, Fig. 265, for 10-horse-power motors is not particularly high for even 5-horse-power motors, I used it for all the motors. I divided the 5-horse-power motors into groups, all working under the same load—five at 10 per cent., five at 20 per cent., five at 40 per cent., five at 60 per cent., ten at 80 per cent. of full load, five at full load, and five at 20 per cent. over load.

The 10-horse-power motors as follows: four at 20 per cent., four at 60 per cent of full load, and two at full load.

These gave a total output of 180 horse-power, and the electric current supplied 246 horse-power. Assuming from Fig. 266 an efficiency of 90 per cent. each for the engine and dynamo, it would require 300 indicated horse-power. This gives a plant efficiency of 60 per cent. with motors on individual machines.

There are very few machines in ordinary machine shops that require more than two or three horse-power to run them, if driven by a motor without belts. If a plant was equipped with a much greater number of motors than I used in my illustration, the motors to be mostly of 1, 2, and 3 horse-power, it is probable that the efficiency would not be reduced very much, as each machine is stopped and started so many times, and the load on each constantly changing.

The sum total of all the machines would maintain a nearly uniform load on the engine and dynamo.

In summing up, Mr. Aldrich says "the group method of elec-

tric driving is much better adapted for small machines up to and including 2-horse-power capacity."

I cannot agree with this statement for several reasons. First, because his last sentence reads, "gross saving about 30 per cent. with direct-coupled motors and 22 per cent. with geared or belted motors." Second, results obtained in three months spent testing power required to drive machine tools lead me to think differently. Last, and more important, because the machine may be designed for, and will give much better results driven by a motor without belts or unnecessary gears.

With the idea in view that the best results will be obtained by using a motor on each and every machine, let us consider the kind of motor to be used.

Mr. Aldrich says "the direct-current motor of to-day leaves little to be desired"; and again, "the induction motor, as it stands to-day, is probably the most perfect motor yet developed from the standpoint of electric transmission in factories and mills."

The first statement is quite correct, but the second needs to be qualified somewhat.

In factories where there are many machines, which from the nature of the work require but one speed, and that as nearly uniform as possible, the alternating-current motor is well adapted to the work. So it is also for long-distance transmission of power.

It seems, from Mr. Aldrich's own statement, that he does not consider the alternating-current system as efficient for short-distance work, for he says "a larger generating power plant is required for an installation of induction motors than would be the case if direct-current motors were used."

I do not agree with him when he says an induction motor is adapted to run machines requiring a variable speed, as do all machines in a machine shop. The best authorities on induction motors say that but two or three speeds at most are possible, and these must be in multiples; that is, for example, 1,000 and 500 revolutions per minute, or possibly 1,200, 800, and 400 revolutions per minute, with no other speeds between.

For driving all machines usually driven with cone pulleys, such as lathes, milling, drilling, and boring machines, the direct-current motor, to quote again, "leaves little to be desired."

The direct-current motor is self-starting, and gives its greatest

pull or torque at starting, and has a wide range of speed with good economy. The speed of the direct-current motor may be varied as much as 6 : 1 and give any number of speeds between these limits.

I have talked with many manufacturers and shop men, who think such a motor is very wasteful of power at slow speeds; but such is not the case, if properly designed. A two horse-power motor may be designed to run at any speed between the limits 300 and 1,800 revolutions per minute, and give an efficiency of 70 per cent. at full load and slowest speed.

This I know, for I designed and built a 1½-horse-power motor for just such work.

This motor, by means of a special controller, runs at twenty speeds, easily and quickly obtained between 310 and 1,900 revolutions per minute, and gives 70 per cent. efficiency at the slowest speed.

In closing I desire to express strongly my belief in, first, Electric transmission in machine shops and factories.

Second, that it is the best method to use motors on each and every machine.

Third, that in machine shops where nearly all machines should be run at varying speeds, to obtain the greatest economy of time for the operators, as well as greatest efficiency in power transmission, the system employing direct-current motors is by far the best.

No. 860.*

HOT-WATER HEATING FROM A CENTRAL STATION.

BY H. T. YARYAN, TOLEDO, O.
(Member of the Society.)

IT does not require the eye of a prophet to foresee the future means of heating and lighting our cities. If heat, using water as a vehicle, can be distributed from a central station covering a territory measured by a radius of one and a half miles from the station, and do it with profit to the investors and entire satisfaction to the consumers, the problem would seem to have been solved. This has been done by the Toledo Heating and Lighting Company for the past five years, a period sufficiently long to place the enterprise beyond the experimental stage, and entitles it to be classed as a successful business venture. It is because I believe the members of this Society will in the future be called upon to exercise their skill and knowledge in refining and perfecting the system that I lay the facts and "state of the art" before you, giving freely results of my own experience, in the hope that it will be of assistance when you are called upon for advice.

I think it will be found that when the new system is generally introduced, in connection with the production of electricity, you will be forced to modify your views on high-pressure steam and the compounding of engines. Where steam economies are of little avail seven months out of the twelve, and where seven months cover four-fifths of the electric output for the year, there would seem to be little encouragement for heavy outlay in that direction. Fortunately for the system, the demands for heat and electricity run almost on parallel lines a large portion of the year. Under the new system electricity becomes a by-product, the only cost of fuel being the condensation of engines, which will average probably twenty per cent. Experience has

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

shown that for every dwelling house heated, it requires the exhaust from engines necessary to light four. It therefore follows that the lighting district must be extended beyond the heating, or some other use be found for the output, such as street railroads, if the entire city is to be heated. If some great genius, like an Edison or a Tesla, were to announce to this Society that electricity could be produced without cost, I imagine there would be a sensation; and yet the Toledo Heating and Lighting Company is doing this very thing, as the six months' business ending January 1st last shows, the load being 190 houses heated and 450 lighted.

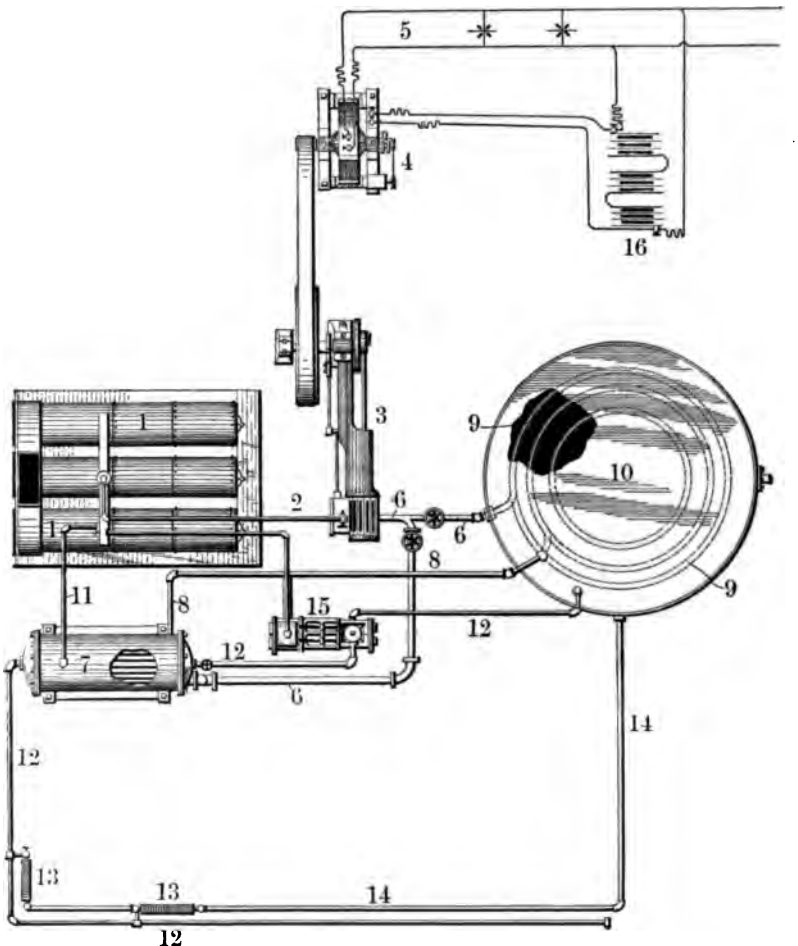
Receipts from heating	$9,900 88
Receipts from lighting	9,064 78

Fuel	$5,040 63	
Wages and salary	2,827 14	
Expense (taxes, repairs, oil, waste, etc.)	1,896 77	
		$9,764 54

I presume the question will be asked why electricity should be treated as a by-product instead of the heat. My answer is, that charges for heat can be fixed and maintained, the consumption of coal increasing proportionately with the number of consumers, while the opposite is true of electricity, and a flexible scale of charges is necessary if the large excess of output is to be disposed of.

Most of you will recollect the disastrous failure in Boston, about twelve years ago, in an attempt to distribute hot water from a central station. A large sum was invested, and the work of installation was of the highest order. I have no direct information as to the causes of this failure, but it is not hard to figure out if one reads the paper of Chief Engineer Abbot before the Boston Society of Civil Engineers. The two mains laid were 4 inches for outflow of hot water, and 6 inches for return. The proposition was to heat water to a temperature of 400 degrees Fahr., and to circulate, necessarily, under a pressure of 250 pounds. He says in his paper that the maximum rate of circulation would be from 10 to 15 feet per second. If I can figure friction, and making a liberal allowance for the less viscosity of hot water, there would be lost in pressure from 3½ to 8 pounds per 100 feet, or at the end of a pipe 3,000 feet from station from 100 to 240 pounds. The effect of this on super-

heated water would be to convert a large portion of it into steam, and the small service pipes of $\frac{1}{4}$ to $\frac{3}{8}$ inch to the various houses would not deliver a sufficiency of the mixed steam and



1. Boilers, 6. Exhaust Steam Pipes, 7. Heater,
3. Engine, 10. Hot Water Storage, 9. Heating Coil,
4. Dynamo, 15. Circulating Pump, 16. Storage Battery.

Yaryan

FIG. 270.

water to heat the buildings. Other troubles would follow in the return pipe. The theory was, that when the pressure was reduced inside the buildings, the superheated water would give

up a large per cent. of steam, and this was to be used for heating; the water returning to the station by gravity, in a closed circuit, to be again superheated. Unfortunately superheated water will give up its steam inversely as the pressure, and as the pressure must be greater at the extreme end of the line than at the station, it follows that, as the return flow reaches points of lower pressure, steam will again be formed until the pumps reach their capacity of handling the mixed volume of steam and water, when circulation would slow down and practically cease. There are many other troubles which they must have encountered that I could mention, but the one given is sufficient, as it was inherent and fatal to the working of such a system. The surprise is, not that the experiment was a failure, but that intelligent engineers should have given their sanction to such an undertaking.

The system I am about to describe and show in plan (Fig. 270) is so simple that but few words are necessary to make it intelligible. The steam boilers, engines, and dynamos are such as may be used in the ordinary electric-light station. Heaters of the tubular type, through which the water passes from the pumps to the mains, receive the exhaust steam from the engines, heating the water to any desired temperature. When more exhaust is being produced than is required to heat the water, the excess is delivered to a water-storage tank to be used later when the output of electricity is small. The circulating system consists of two wrought-iron pipes, laid side by side in the ground, carefully protected by insulation, one pipe for the outflow of hot water impelled by the pumps, the other for the return water from the coils in the various houses heated, going back to the suction end of the pumps, to be forced again through the heaters, where the loss in temperature is restored.

The Toledo Heating and Lighting Company has two stations, known as the Floyd Street and the Twenty-second Street stations, and although the heating mains of the two stations are separate and distinct, the dynamos of the two stations feed into a common system of electric mains. The length of the double water mains, that is ditch, connected to the Floyd Street Station is 8,550 feet, and the number of houses heated is 101. The length of mains from Twenty-second Street Station is 8,260 feet, and the number of houses heated is 98. The amount of radiating surface connected with the Floyd Street Station is about

PIPE LINES
OF THE
FLOYD ST. STATION
SCALE: 200 FT.
PARKWOOD
ACKLIN
AVE.
VIRGINIA
BATAVIA
ASHLAND
COLUMBIA
BANCROFT
ST.
W. BANCROFT
AVE.
COLLINGWOOD
PRESCOTT
FLOYD
ST.
FLOYD
HORTON
PARKWOOD
AVE.
IRVING
SMEAD PL.
W. WOODRUFF
AVE.
W. WOODRUFF
AVE.
MADISON
MONROE
ST.
JEFFERSON
ST.
3 in.
4 in.
T. Faryan

FIG. 271.

90,000 square feet, and with the Twenty-second Street Station about 85,000 square feet. The amount of coal consumed at both stations during the heating season, from October 1st to May 1st, averages 5,000 short tons of coarse slack, or about 25 tons to the residence. These same buildings, if heated by their own furnaces, would average not more than 18 tons of hard coal each. The difference may be accounted for by the loss of heat in ground radiation, and largely by the fact that we heat the

FIG. 272.

buildings more thoroughly and for a greater number of hours than they could or would do by private furnaces. The loss of heat through radiation in our mains is an important one, and I am sorry not to be able to give positive data, but it is impossible to more than approximate the loss. From careful observation, I estimate the loss to be between 15 and 20 per cent. The water reaches the extreme end of our lines, three-quarters of a mile from the station, in the coldest weather, with a loss of 12 degrees Fahr., which would be an average of 6 degrees to all

of the houses. As the water returns to the station with a drop of 35 degrees, this would indicate about 17 per cent. loss in the ground, which I believe to be nearly correct. A pressure of

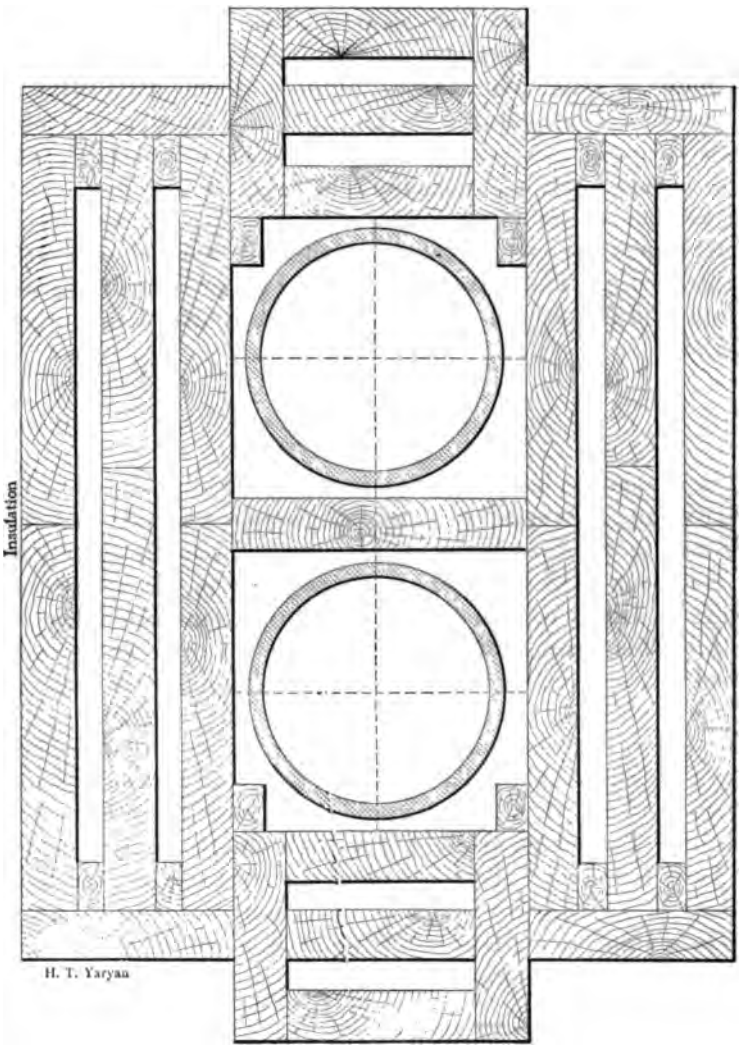


FIG. 273.

60 pounds is maintained on the feed line during cold weather and 40 pounds during moderate weather. The service pipes to the various houses are 1-inch pipe, and the return line throttled

with a disk inside the building, the size of opening depending upon the quantity of radiation, but average $\frac{5}{8}$ of an inch. The houses are equipped with radiation sufficient to heat them to a temperature of 70 degrees Fahr., with water entering the house at 160 degrees Fahr., when the outside temperature is freezing. By raising or lowering the temperature of water one degree for each degree of variation in the outside temperature, we are able to maintain a constant temperature in the houses during all kinds of weather. There is no occasion for the consumer to regulate the flow of water during the entire winter, and with few exceptions our consumers open the supply valves in the fall and only close them in the spring. The extreme limits of temperature of the water is from 130 degrees in moderate weather to 212 degrees in the coldest.

Insulation.

The insulation used is shown in section, Fig. 273, and is both effective and inexpensive. The top, bottom, and sides are made in separate sections by using for top and bottom three 1-inch boards, separated with $\frac{1}{2}$-inch strips to form air spaces, with 1-inch by 4-inch boards on the sides to prevent the entrance of earth. This manner of insulation is as near perfect as can be hoped for, and the only improvement which might be suggested is to creosote the outside boards. After four years of use, the only sign of rotting is in the outside boards which come in contact with the earth. The heat in the mains keeps all other boards perfectly dry, and it would seem that their life was indefinite. The mains are laid in a ditch only 30 inches deep, as we have found by experience that the nearer they are to the surface of ground the less loss by radiation. The reason for this is simple enough, as wet ground is a better conductor of heat than dry, and the deeper you go the longer the ground remains wet.

Heaters.

The heaters are really surface condensers, and I have some hundreds in use for this purpose, the only novelty about them being the manner of providing for the difference in expansion of

copper tubes and iron shell. No thimbles or other devices are used to permit a slip through flue sheets, but each tube is rigidly expanded in the top and bottom flue sheet. They are

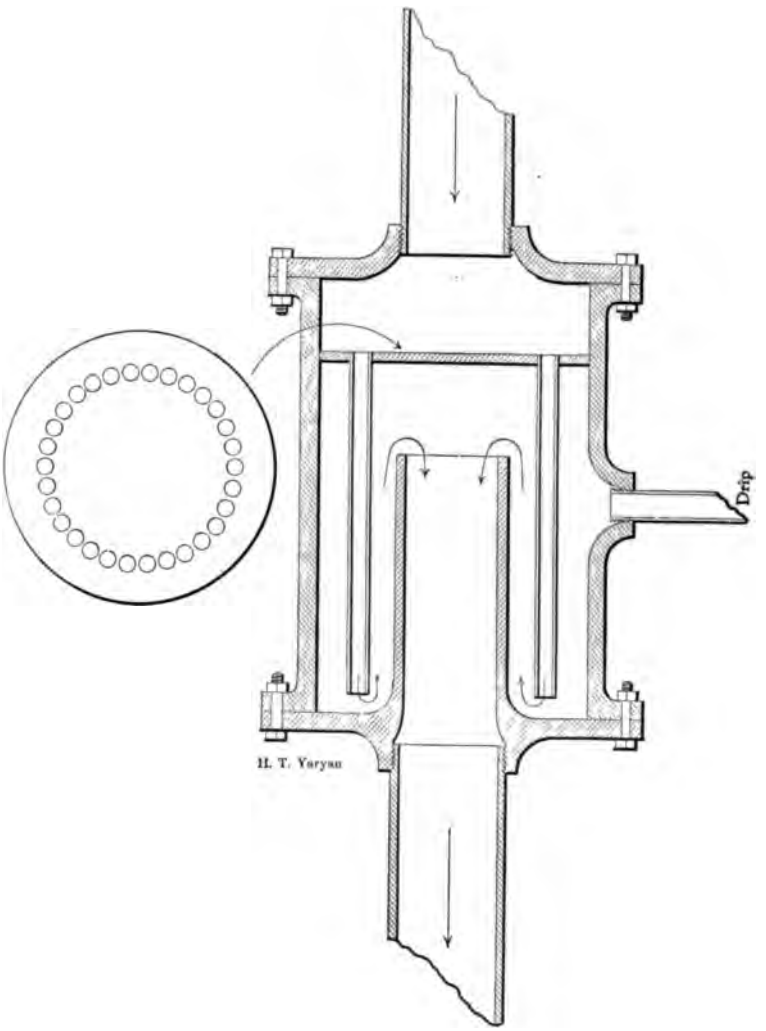


FIG. 274.

7 feet long, 24 inches in diameter, and contain 500 $\frac{5}{8}$-inch copper tubes. The tube before entering is bent so as to make a permanent sag of $\frac{5}{8}$ inch, which is intensified to about $\frac{3}{4}$ inch in expanding, by the use of a drift.

Grease Traps.

As all the water of condensation is sent back to the boilers, a thorough separation of oil is necessary. I have found most of the so-called traps a delusion, as they depend upon slowing down the steam current to permit the particles of oil to be dropped. The finer particles, however, are so thoroughly entrained that they are carried to the condensers and thence to the boilers. The trap shown in Fig. 272 was really constructed to separate entrained salt water, in distillers on shipboard under a vacuum, where the speed of vapor is high. The principle involved is separating the volume of vapor into jets by passing through 1-inch tubes equal in area to the exhaust pipe, so that only a narrow space intervenes between the end of tube and impinging surface. The smallest particle of entrained substance is carried over this space by its own momentum, and is held by the impinging surface, where it runs off through the drain pipe. Incidentally, I may state that fully one-half of the oil used on engines and pumps is recovered and used over again.

Expansion on Mains.

The provision for expansion on underground mains is of vital importance. After trying all manner of devices, the ordinary U, where the run is straight, and 90-degree bends at corners, answer the purpose admirably and give no trouble whatever. The U's are placed about 600 feet apart, and as the extreme expansion is about $\frac{3}{4}$ of an inch to 100 feet, only $4\frac{1}{2}$ inches are necessary to be taken care of by each U. As the mains are laid cold, we put an extra strain when laying on the U's in an opposite direction to that in which they work when allowing for expansion.

Corrosion of Mains.

Almost the first question asked by a practical engineer is, How about the corrosion of your pipes? I am happy to say that I can answer this question in a satisfactory manner, as over 10,000 feet of pipe were relaid last summer, after being in use 5 years. The wrought-iron pipe showed no signs whatever of corrosion, but steel pipe was perceptibly affected. There was a great difference in different lengths of steel pipe, but all were

affected more or less. The appearance of the pipe showed the formation of nodules on the inside, varying in number from one dozen to 100 in a length of pipe, and in size from a grain of corn to a hazel nut. When the nodules were removed, a soft underlayer of carbon remained, and with the finger nail this could be removed, developing a perfectly round pit from $\frac{1}{8}$ to $\frac{3}{16}$ of an inch deep, but in no instance had the pit perforated the pipe. As a matter of curiosity, some steel pipe which had been in use two years was examined, and found to be in exactly the same condition as that of 5 years' use. The action seems to be electrolitic, some particle of impurity forming the nucleus for decomposition of the steel. If any inference can be drawn from the facts stated, it is that the impurity has lost its power to cause electrolysis after being surrounded by a sufficient amount of graphite. The most important lesson taught, however, is that only wrought pipes should be used for water circulation.

Friction Loss in Mains.

A test with pressure gauge on the outflow pipe at the extreme end of our lines shows 39 pounds with 60 pounds at the station, or a loss of 21 pounds due to friction. At the same time the pressure on the return line was 28 pounds, and as the friction should be the same on both lines, the difference may be accounted for by the fact that the return line discharges into a tank 15 feet high at the station.

In calculating the size of mains for a given number of houses, it became necessary to know the relative friction of hot water as compared with cold. To my surprise, I was unable to find any data that were of value, and to settle the question I made some tests which may be useful in future work. A run of 450 feet of 1-inch wrought-iron pipe with numerous bends was connected to a heater, and the water passed through a meter. With a constant pressure of 10 pounds the following cubic feet of water were delivered at the open end of the line in 5 minutes:

At 34 degrees Fahr.....	6.2	At 150 degrees Fahr.....	6.6
" 60 " "	6.3	" 185 " "	6.75
" 90 " "	6.4	" 212 " "	6.9
" 120 " "	6.5		

As it requires an average of 15 gallons per minute to be delivered at each house, and knowing the friction of cold water, the

data thus obtained enabled me to calculate the size of mains necessary to give good service to each house, and to always maintain a sufficient difference in pressure between feed and return mains to insure rapid circulation.

Steam vs. Hot Water.

As exhaust steam heating from central stations has been introduced to a limited extent, it may not be out of place to call attention to the objections to steam, which do not apply to hot water.

1. The exhaust not being uniform in power plants throughout the entire period of 24 hours, either live steam must be used during the minimum load, or exhaust must be lost during the maximum load.

2. The excessive cost of laying steam mains, which must be large and thoroughly protected from infiltration of water. The temperature of pipes being above the boiling-point of water, any infiltration is converted into steam, and thus a vast amount of heat is dissipated.

3. It is absolutely necessary that from 5 to 15 pounds back pressure shall be carried on the engine, which is exceedingly wasteful.

4. The condensation of steam is wasted, and with it a large percentage of heat.

5. The piping of houses is expensive on account of the large size required to convey steam with 1 or 2 pounds back pressure.

6. The service is not satisfactory on account of difficulty in regulation, especially in mild weather.

7. The offensive smell, due to vents and leaky stuffing boxes.

8. Water hammer, due to condensation in house pipes.

9. The quality of heat, especially where direct radiation is used.

10. Danger from fire, which has been abundantly demonstrated, can arise from long-continued contact of steam pipes with wood, in an enclosed place.

11. Greater loss by radiation in ground, due to an average higher temperature of mains.

12. The necessity for sewer connections to remove condensation in mains where traps may form.

13. The rapid destruction of all iron drips, due to the solvent action of distilled water.

14. The filling of the entire system with air when a shut down occurs for any length of time.

The only counter charge I have ever heard made was, that it required live steam to run the pumps. But this is largely offset by the back pressure on engines in the steam system and can be made a large source of profit by selling the heat, as none is wasted.

During the past two years the system I have described has been installed, and is now in successful operation in the following cities and towns: La Porte, Ind.; Matton, Ill.; La Crosse, Wis.; Kenosha, Wis.; Alton, Ill.; Portage, Wis.; Boone, Perry, Ida Grove, Iowa Falls, and Mason City, Iowa.

During the present summer the company which I represent will install a refrigerating plant for domestic use, distributing cold brine in exactly the same manner that we do hot water, but using a separate set of mains. We shall use an ammonia-absorption machine, operated with exhaust steam, so that as the demand for heat ceases that for cooling purposes begins, thus utilizing the exhaust steam from our engines during the summer months, which now goes to waste.

DISCUSSION.

Mr. Frederick A. Waldron.—There are a number of points in the paper to which our experience in the past year in the plant of the Yale & Towne Manufacturing Company, Stamford, Conn., would warrant us in taking an exception.

In Mr. Yaryan's summary of "Steam vs. Hot Water," in paragraph 3 the statement that 5 to 15 pounds pressure is absolutely necessary on an engine is not verified by our experience in the past winter, as the heating system which we have in operation is able to heat our building the entire winter on an average pressure of 13 pounds absolute. In other words, our main engine has run through the entire season with an average vacuum of about 4 inches.

PARAGRAPH 4. With a large system of pipes and proper oil separators, the entire amount of condensation is practically returned to the boilers. During the entire season we have not, with one exception, seen a single puff of exhaust steam or a

vapor of any description whatever appear at the exhaust head of our engine.

PARAGRAPH 6. "The service is not satisfactory on account of the difficulty in regulating, especially in mild weather." We have found, owing to the lower temperature of steam at 10 or 12 pounds absolute, that we are enabled to obtain very satisfactory results in this direction.

PARAGRAPH 8. "Water hammer due to condensation in pipes." Regarding this matter, we have not had even a single sound or crack in any of our pipes.

PARAGRAPH 9. "The quality of heat, especially where direct radiation is used." With the low temperature of steam as mentioned under paragraph 6, we find the quality of heat very much improved over the heat with a pressure of 15 pounds per gauge.

PARAGRAPH 10. Danger from fire. With low temperature of steam, we think the danger from fire is nil.

PARAGRAPH 12. "The necessity for sewer connections to remove condensation in amounts where traps may form." With a vacuum system and proper vacuum on the pump this is unnecessary, as the vacuum will lift a number of feet with the proper thermostatic valve installed at the points requiring drainage.

PARAGRAPH 13. "Rapid destruction of iron drips due to solvent action of distilled water." Since shutting down our system for the winter we had occasion to take down some of the coils, and we found the inside of these coils to be absolutely dry.

PARAGRAPH 14. The filling of the entire system with air when shut down for any length of time. This is true, but with proper valves and vacuum pump a defect of this kind does not appear at all detrimental.

In connection with the above we would say that the exhaust from our vacuum pump passes into the heating system, so that all that is lost in running the pump are the losses due to radiation and condensation on the cylinder on the vacuum pump.

Mr. W. F. Mattes.—I am quite sure that members of the Society generally will feel indebted to Mr. Yaryan for his interesting and instructive paper, and will also be disposed to congratulate him upon his showing of a successful enterprise so well conceived and so critically carried out. Nevertheless, when he confidently undertakes to forecast the future of heat and light

distribution perhaps he would do better to get that discarded "eye of a prophet" in proper working order, for otherwise we are bound to have a little fun with him.

In his opening proposition, like Esaias, he is very bold. He says, "It does not require the eye of a prophet to foresee the future means of heating and lighting our cities. If heat, using water as a vehicle, can be distributed from a central station covering a territory measured by a radius of one and a half miles from the station, and do it with profit to the investors and entire satisfaction to the consumers, the problem would seem to have been solved."

This forcibly reminds me of the old saw, "One story is good until another is told." If the first story is perfect it will never be excelled, but it is well for human enterprise that the chance for improvement always remains with us.

The foremost essential of any such distribution scheme is that the element distributed shall supply as largely as possible the needs of the people. The second is that the cost to the consumers shall be as low as practicable. It is to the extent that Mr. Yaryan's enterprise has fulfilled these conditions that his well-merited success is due. But the limitations of the hot-water, as well as the steam system may easily be drawn from the text of his paper. I will mention only the most noteworthy. First is the loss of heat by radiation and otherwise from the mains and service pipes. Second, it furnishes heat for one purpose only. It will heat the house, but it will not heat the dinner—it will not roast the turkey nor bake the flapjacks. Third, as regards hot water at least, it supplies no power. It toils not, neither doth it spin. It will lend no active hand in our industries, be they public or domestic. It refuses to drive a planing machine or a sewing machine, to grind wheat or coffee, rock the cradle or spank the baby. It is true that Mr. Yaryan springs upon us the startling discovery that electricity is a by-product of hot water, whereas we would as soon have classed Jersey lightning as a by-product of the Young Men's Christian Associations; but upon looking into that claim we find that he is able to light 450 houses against only 199 heated, and the inference is either that it costs about twice as much to heat a house by distributed hot water as to light it by distributed electricity, or that the two divisions of his plant and service are not well balanced.

I announce no fresh discovery, but only mention that known to all, in asserting that there is an element more easily distributed than water, and without appreciable loss in transmission, passive in transportation and active only at the point of application, requiring no insulation nor return pipes, and capable of yielding heat, power, and light. Perhaps, after all, a good nose in the neighborhood of a gas producer would be more servicable to Mr. Yaryan than the aforesaid eye of a prophet. It would at all events enable him to "smell the rat" that is likely some day to crawl through his hot-water pipes.

Probably it would be inappropriate to this discussion to attempt to deal with the numerous questions that arise in connection with the manufacture and distribution of gas for the purposes indicated, throughout our cities and industrial centres. The natural-gas fields are necessarily limited in area and yield, and, outside of them, the choice between water, coal, and producer gas will be of primary importance. There is also the serious question between the illuminating and non-illuminating varieties. The latter will yield light by incandescent burners or, what is likely to be of more importance, it will supply electric lights by the agency of gas engines.

We all know that much has already been done in the way of distributing gas, mostly the natural article; but I think few engineers, and still fewer of the general public, realize what will probably be done in the opening decade of the twentieth century. I am convinced that before half that period has passed we will have at least one pipe line from the anthracite fields of Pennsylvania to the seaboard. To a thoughtful citizen of Scranton the immense accumulations of anthracite waste are very suggestive. Much has been done to utilize them in generating steam by the aid of suitable grates and jet or fan blast, but that hardly scratches the subject, and least of all for distant localities. Much interest has been awakened by the starting of the large Otto-Hoffman plant at Boston, where fuel gas issues as a by-product of the coke manufacture, and undoubtedly the field for such a process is very large and important, but it will also be interesting some day to study the boundary line between that field and the territory that can be dominated by cheap gas piped from the mines. There may also be some exhilarating statistics, under the heads of transportation and relative values, in the case of gas in pipes versus coal on rails.

The next great step to be taken in that direction is to develop a simple and satisfactory method of manufacture from pulverized fuel, such as Pittsburgh slack and anthracite culm mainly consist of. No such method has yet been made public to my knowledge, but there is more than one reason for believing that practical success is not far distant.

Mr. Jewett.—It may be of interest to the Society to know that two of its members, Mr. Q. N. Evans and Mr. J. A. Almirall, of New York City, have been installing similar systems in the East for the last ten years. They have in many instances heated a large number of manufacturing buildings from a central point, as well as town-heating plants, involving practically the same principles, and some of the features of their system and some of the differences from this system may be worth mentioning.

The storage tank which Mr. Yaryan has described is a very attractive proposition. If the surplus exhaust could be stored in a tank for use at times when there is no exhaust steam, that would seem an ideal proposition. But when one comes to examine the subject closely and to figure out the size of the tank that would be required to store up sufficient heat to be of any value, he finds that it becomes a practical impossibility. In other words, the Floyd Street Station at Toledo is connected with 90,000 square feet of radiation. It would be fair to assume that each square foot of radiation calls for an average supply of 150 heat units per hour. That is, this system must be supplied with 13,500,000 heat units per hour. If water is circulated through the system and drops 35 degrees in the circuit, each pound of water circulated will give up approximately 35 heat units. Then to store up water enough in a tank to supply the system for one hour, there would have to be stored up some 385,000 pounds of water, or 46,000 gallons. This makes a tank of quite large proportions, and few plants have the room in which to place such a tank or the money wherewith to build it. If it is desired to make the tank big enough for six hours' supply, the tank becomes larger than the electric-light plant itself.

In addition to this feature of the storage tank, it is of necessity an open spot in the circuit. The radiators on the second, third, or fourth floors of buildings cause a static head on the lowest point of the system of considerable amount. It would be impracticable to make so large a tank strong enough to withstand the static head, so that the tank must be an open one.

The pump drawing from the tank must then lift the water to the top of the highest radiator, and the water flowing back from that radiator to the station runs into the tank. That is, no benefit is obtained from the flow of water down the return side, and the pump is not only circulating the water, but is lifting the entire water. If the return pipe were connected direct to the suction end of the pump, and no tank of that description were in the circuit, then the static head on the suction side of the pump would be equal to the static head on the discharge side, and the only work the pump would have to do would be to overcome the friction in the circulation. In the system installed in the city of Red Oak, Iowa, the pump operates against a net pressure of 13 pounds only. In circulating water through three-quarters of a mile of pipe, the static head on the pump amounts to about 33 pounds. The gauge on the suction side of the pump shows 26 pounds and the gauge on the discharge side shows 39 pounds, the pump working against only 13 pounds pressure. That being true, and the pump working against so small a head, there may be used a different and a more efficient type of pump than the duplex pumps used by Mr. Yaryan. Where the pressure runs up above 30 pounds, it is necessary to use a plunger type of pump; but with a low pressure of 10 or 20 pounds, the centrifugal type of pump may be used, and this pump may be driven from a Corliss engine, giving a steam economy of 26 or 27 pounds. Or it may be driven by a little direct-connected high-speed engine or motor, at the most requiring a steam consumption of 40 pounds per horse-power hour, where a duplex pump would require 120 or 150 pounds of steam per horse-power hour. I cannot agree that it makes no difference how much power the pump takes to circulate the water, because there are always times when there is sufficient exhaust steam to do the work, and any extra power required in the pump is so much power thrown away.

The system installed at Red Oak has a one-pipe circuit. It is a single-pipe system; that is, the one pipe is carried up one street and back down another street to the station. All the connections are made from the one pipe, the connections to the houses being shunts, working out precisely as electric shunts. The flow of water in the building is inversely proportional to the resistance in the piping of the building and the resistance between the two T's in the main. That system has been

installed and is in operation, and the actual drop in temperature of the water after passing three-quarters of a mile of pipe and 15,000 feet of radiation is only 9 degrees.

At times heat must be supplied to the system through some other source than exhaust steam, because occasions arise when there is not sufficient exhaust steam to do the work. Under the Evans system an extra live-steam heater is installed and live steam taken from the boiler into it, this heater being placed high enough above the water line of the boiler so that the condensed live steam, when used, will be returned directly to the boiler by gravity without any trap or return pump. This is superior to blowing live steam into the same heater with the exhaust steam, in that it does not mix live steam with the exhaust steam, but keeps it separate. And the condensed live steam does not have to be pumped back to the boiler. When live steam is blown into the exhaust pipe it is absolutely essential that a back-pressure valve be placed in the exhaust pipe, so as to provide pressure against which the reducing valve may work. This system works out in its many details very practically, and as installed at Red Oak has been very profitable and satisfactory to the Red Oak Electric Company.

Mr. Yaryan.—Referring to Mr. Waldron's discussion, he has confused isolated steam plants with central-station distribution, to which I referred. I have nothing to say against the isolated steam plants as generally operated, and especially with the vacuum system. They are practical and meet with success, but the vacuum system is absolutely impracticable in a central-station distribution. In practice they are compelled to waste their drips, and with it a large amount of leak. If Mr. Waldron did not lose exhaust during the past winter, it was because he had none to waste. There is a constant temperature of steam at a given pressure or vacuum, and hence regulation at a central station is impossible. It is possible to avoid water hammer in steam systems, but as generally installed the fault is a common one. With low temperature of steam, as in the vacuum system, the quality of heat is improved; but, again, the distinction between isolated plants and central-station must be referred to. It is found in practice that the drips in street mains must be connected with the sewer. As to the rapid destruction of iron pipe by the solvent action of distilled water, I am only stating a fact. Where the condensation occurs in an exhaust steam pipe

no erosion takes place, on account of an appreciable amount of cylinder oil protecting the iron, which is not true when distilled water is passing through an iron pipe. There is not one of you gentlemen who has had occasion to pump the condensation of your condensers back to your steam boiler, but has had to replace the iron pipes every year. It is the peculiarity of distilled water that it absorbs its percentage of iron, and repeats it until the iron is eroded and destroyed in an appreciable time, which is not true when there is exhaust steam condensed in pipes, because there is a certain amount of cylinder oil that will protect the surface of the iron from erosion.

As to the storage tank, it has not been the intention to use a storage tank for any other purpose than taking the excess of exhaust, which, when a plant is fairly well balanced, is not considerable. I have at the Floyd Street Station a 75,000-gallon storage tank. In mild weather the exhaust from the engine during the peak of the load, which runs from an hour to two hours, is quite in excess. As near as I can figure it out, I can get the absorption of the heat from about 3,000 pounds of coal in that storage tank during an evening, which is done every day. In cold weather we have no excessive exhaust, but as the spring and fall come, as the weather moderates, we have got a large excess of exhaust, and that is simply a question of the size of tank. I cannot agree with the gentleman that even a 500,000-gallon tank is such a tremendous affair. Of course, if plants are so located that they cannot build a storage tank, that is a misfortune, but 500,000 gallons is not a tremendous tank, and it will take the exhaust from a great many engines for a limited time.

He speaks of the circulation lasting only an hour or two hours. The water is heated to 212 degrees, and in mild weather we are circulating water at 140 to 160 degrees. It takes a very small quantity of water to raise our temperature up so that our storage tank in practice runs six hours, maintaining its temperature. As the electric lights increase I am compelled to put in a larger tank, but they pay for themselves very rapidly. It enables you to make an unequal load an equal one, so that if one desires to throw away that 3,000 pounds of coal every evening, of course he can do without a storage tank. So far as I am concerned, I prefer to save it.

Mr. Daniel Royse.—There is one question which I would like

to ask. Near the bottom of page 943 it is said: "The service pipes to the various houses are 1-inch pipe, and the return line throttled with a disk inside the building, the size of opening depending upon the quantity of radiation, but averages $\frac{5}{8}$ of an inch." And immediately preceding it is stated that the pressure maintained on the feed line in cold weather is about 60 pounds. I would ask the reason for maintaining such a high pressure on the supply side of the line and then throttling the return. Why not make the return open and have the pump work against a smaller pressure on the supply line?

Mr. Yaryan.—That is a very proper question. The reason is that we heat buildings four stories high, and it is absolutely necessary that we should have enough back pressure to raise the water to the highest story. Then, again, it enables us by carrying 60 pounds steam to use a very small pipe. We are allowed a large margin for friction. As I have shown in my paper, in $\frac{3}{4}$ of a mile we have some 21 pounds friction, and we still have an available working pressure between the feed and return line sufficient to cause rapid circulation. If we allowed a free opening, we would simply run too much water through the houses near the station. We throttled it so that the proper amount of water can go to each house, and at the same time have sufficient back pressure to carry the water to the higher stories. We are unable to put any back pressure on our return lines. We have it free and open, emptying into a tank 15 feet high, and find that we economize the size of our mains by doing it. As exhaust steam from those pumps is all utilized, it is not an important matter to us, as we take on a sufficient heating load to be able to use an extravagant direct-acting steam pump and still waste no exhaust.

Mr. Wallace.—The remarks that I have to make have been largely anticipated by the gentlemen who have already spoken. I have listened to these papers with very great interest. My work for the last fifteen years has been largely along heating lines, and I am convinced that a perfected central system for the distribution of hot water will prove exceedingly popular as well as profitable. The limitations seem to be mainly friction and loss by radiation. These have their economic limits, which, of course, are not difficult to determine. But it seems to me that the loss by radiation, estimated by Mr. Yaryan, is unnecessarily high. See what it means in connection with his Toledo plant:

A saving of 1 per cent. of the loss, which he estimates would mean the heating of at least two more houses and an added revenue of at least $200 per year. The deductions from this fact are not difficult to make. If $4,000 will provide better insulation and save 1 per cent. of this loss, it will certainly pay to expend it, figuring from this standpoint alone. There is the added advantage of being able to heat the same number of houses with smaller mains, which, at present prices of pipe, is perhaps the greater advantage of the two. The matter of the storage tank also came to my mind, and I intended to ask Mr. Yaryan what sized tank he is using at Toledo. The thought came to me that the tank must necessarily be of considerable dimensions in order to be of much advantage. That point he has already explained.

In reference to modifying our views in regard to economical engines, I do not agree with his conclusions. As the heating season covers only a part of the year, I think that true economy will be conserved by using economical engines as a rule, and providing for any shortage which there may be in the supply of heated water by getting it from first hands; that is, from a boiler provided for that purpose. I do not see the economy in using low-duty engines in order to get the exhaust steam from them to heat the water a portion of the year, when it can certainly be done at less expense by providing a boiler for that purpose.*

I had the pleasure of inspecting a plant installed on the system Mr. Yaryan has described at Mattoon, Ill. They stated to me then that the maximum drop in temperature in cold weather at the end of their longest line was 8 degrees, which is a better showing than Mr. Yaryan claims for his Toledo plant. The main on which this temperature was taken is a mile and a quarter long, and the last two blocks of pipes are only 2 inches in diameter. There are three houses warmed on the end of the main, and the work of heating seems to be done with perfect satisfaction. I question the economy of using such small

* Some exception was taken to this statement, owing, I think, to a misunderstanding of it. My proposition is not to use live steam to supplement the exhaust, but to pump a part of the water through a special boiler, which may be placed in the path of the furnace gases as an economizer, or may have its own fire under it. Of course, if condensing engines be installed, they should probably be able to carry the load non-condensing during the heating period.

pipes, but they seemed to get satisfactory results from the heating.

Mr. George I. Rockwood.—I want to indorse the general idea of the author of this paper and to speak of a method of heating water which seems practically the same method described, but which is in use in dye houses in textile mills. I cannot indorse the remarks of Mr. Wallace, when he says that it is better to use what he calls an economical engine and generate the steam for heating by means of live steam. In a case where you can use up all the heat exhausted by the engine, it seems absurd to throw so useful a by-product away and evaporate water anew for the heating. If you cannot use up *all* the steam which the engine exhausts, how much of it can you use? And if it is an insignificant proportion, then would be the opportunity to use your economical type of engine; that would be true economy.

I have in hand now a case of a colored-cotton mill where they use a great deal of hot water. It is their present practice to heat this water by introducing live steam. At the same time they are running a pair of 30-inch by 72-inch Corliss engines condensing.

I am planning to do for this dye house exactly what Mr. Yaryan does in his hot-water heating system. That is, I am providing a 50,000-gallon tank to store the heat received from the exhaust of this pair of Corliss engines, running them hereafter non-condensing. The heat is to be added to the water in the tank by mixing the water to the steam at atmospheric pressure in a Bulkley 16-inch condenser. As the present demand for steam in the dye house is very irregular, I hope to effect a great reduction in the number of boilers hitherto required to be constantly under steam.

*Mr. H. T. Yaryan.**—If Mr. Mattes displayed as much talent as a prophet as he does as a humorist, we would be justified in preparing for the millennium, when all our houses would be heated with producer gas made from culm piles and slack dumps of the coal regions. His proposition lacks even the novelty of being new, since we have heard the same thing proposed periodically by persons who either do not or cannot comprehend the impossibility of such an undertaking. Fortunately we have some data as to the distribution of gas for heating purposes in

* Author's closure, under the Rules.

our natural-gas fields, and we can use this to demonstrate the fallacy of trying to distribute producer gas. The heat units of natural gas are about 1,100, as against 125 in producer gas. In the city of Toledo, when it was practically heated with natural gas, it required the equivalent of a 24-inch main from the fields thirty miles away, with gas at 450 pounds pressure, to supply the city. With producer gas it would have required nine such mains to give the equivalent in heat units. Again, how many cities are located within a radius of 30 miles of the culm dumps that he refers to? The actual cost of laying mains from gas fields and throughout the city has been over $2,000,000, so that one can imagine the cost of mains to carry nine times the volume, and the capital invested in pumping stations, even for so short a distance as 30 miles. Then consider what it would be for 100 miles, and the proposition to run machinery at the Paris Exposition from power generated at Niagara Falls seems by comparison to be not far out of the way. In predicting what is in the future for hot-water distribution from central stations, I do not draw upon my imagination to any great extent. What has been done in the past five years demonstrates that the system is practical and profitable. A proposition containing those two elements is bound to be generally adopted sooner or later.

No. 861.*

THE GAS-ENGINE HOT TUBE AS AN IGNITION-TIMING DEVICE.

BY WM. T. MAGRUDER, COLUMBUS, OHIO.

(Member of the Society.)

THE series of tests of a gas engine, the data and results of which it is here desired to record, was made as part of the regular post-graduate laboratory work in gas enginery, given by the writer at the Ohio State University at Columbus, Ohio, during the college year 1898–9, by Mr. F. J. Hale, M.E., class of '98, and Mr. Horace Judd, M.E., class of '97, as part of their elected work for their post-graduate degrees. Mr. Hale had previously assisted in making over fifty tests of gas engines under eighty horse-power in size; while Mr. Judd had been for more than a year an assistant in the mechanical-engineering laboratory. Both young men were unusually painstaking and careful observers, and it is therefore thought that the data and results are trustworthy. Most of the indicator diagrams here presented were taken by the writer. The results have been worked up chiefly by Mr. Hale, and have been checked by the writer and one of his students.

The engine tested was rated at 9 indicated horse-power and at 7 brake horse-power when using natural gas and running at 280 revolutions per minute. It may be classified as a 4-cycle, scavenging, horizontal gas engine having a single cylinder of 6-inch diameter and 12-inch stroke. The lay shaft was driven by spiral gears from the crank shaft at one-half the latter's number of revolutions per minute. Cams on the lay shaft caused the inlet and exhaust valves to open once in every two revolutions of the crank shaft. The governor was the usual type of hit-or-miss inertia pendulum governor, actuated by a cam on the lay shaft and propelled by a spring; and hitting or

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

missing, as the work and the speed of the engine demanded, a tappet on the end of the gas inlet-valve spindle, whereby gas was admitted to the mixing chamber, whence the mixture of gas and air, or the air alone, passed through the inlet valve into the ignition chamber, and so into the combustion chamber, or cartridge space, of the engine cylinder.

About 25 tests of this engine had been made during the preceding college year, so that it is thought that the newness of the engine had been worked off, and that both valves and journals had become adjusted in their bearings.

The method of testing was the usual method employed in this laboratory for testing gas engines. A full description of the gas-engine testing plant may be found in Vol. VII., page 122, of the *Proceedings* of the Society for the Promotion of Engineering Education, in a paper presented to that society by the writer at its Columbus meeting, in 1899, on "The Hydrocarbon-engine Testing Plant of the Ohio State University." For the purposes of this paper, however, it should be stated that the power gas for a test is collected in a gasometer of 225 cubic feet capacity, which is graduated into cubic feet, and so that readings may be easily estimated to one-tenth of a cubic foot. From the gasometer, the power gas is forced by city water pressure to the engine through an ordinary tin gas meter, whose readings are used solely for the purpose of checking. The pressure of the power gas is measured by a water manometer connected to the gasometer, and is regulated by the observer who is stationed at the water-inlet valve. By this means almost any desired pressure may be obtained. The power-gas pipe leading to the engine is $1\frac{1}{2}$ inches in diameter, while the engine's gas cock was $\frac{3}{4}$ inch. The air inlet of the engine was tapped for $1\frac{1}{2}$-inch pipe, into which was connected a $1\frac{1}{2}$-inch close nipple, a $1\frac{1}{2}$-inch by 2-inch reducer, a 2-inch close nipple, and then a 2-inch malleable-iron pipe union, so that the air of the room entered the engine through these fittings in the reverse order to that here given. In order to regulate or throttle the air supply, circular orifices made with sharp edges in thin planished iron were inserted between the two halves of the 2-inch pipe union.

The gas for the Bunsen burner of the hot tube was taken from the main and measured by a separate 5-light tin meter, and had no relation to the power gas except that it came from the same street main.

The exhaust gases passed by a 2½-inch pipe through the usual exhaust pot, and so by a 2½-inch pipe to the atmosphere.

The jacket water entered the cylinder jacket below the combustion chamber, and passed out above at the front end of the cylinder. Its temperatures were measured by chemical thermometers whose bulbs were immersed in cylinder oil in thin-walled brass thermometer cups inserted in pipe fittings through which the jacket water was passing. The engine was so piped that the jacket water could be weighed either before or after it had passed through the cylinder of the engine.

No attempt was made in this series of tests to measure the quantity of air consumed, although ample facilities were at hand, as a previous series of 25 tests had been made on this point, and tests made with the engine receiving air at from 4 inches of pressure to 19 inches of suction. Neither were the exhaust gases analyzed. The gas used was ordinary Columbus coal gas. Its composition is accepted as reported below by the analysis of a sample made by Mr. Frank Haas, C.E., E.M., of the department of metallurgy of the university, and under the direction of Prof. N. W. Lord, E.M.

ANALYSIS OF GAS.

Illuminants (C_2H_4)	7.7	per cent.
CO_2	.4	"
O	2.4	"
CO	5.3	"
H	50.5	"
N	9.0	"
CH_4	24.7	"
	100.0	"

Its calorific value, as determined from this analysis, is 584 British thermal units per cubic foot of the gas at 32 degrees Fahr., and at standard barometric pressure (29.92 inches of mercury). Its calorific value, as determined by these chemists in the Mahler bomb calorimeter of the department of metallurgy, is 564 British thermal units per cubic foot of gas under the same conditions.

The indicated horse-power was obtained by means of a new Crosby gas-engine indicator and an "Ideal" reducing motion, which received its motion from a stout iron arm rigidly secured

to the piston of the engine. The straight indicator cock was screwed directly into the top wall of the combustion chamber. The brake horse-power was obtained by a rope brake resting on a pair of double-beam platform scales, and whose rope encircled a water-cooled brake pulley. The revolutions of the lay shaft and the admissions of gas per minute were obtained by electric counters, either or both of which could be thrown into or out of action by the observer at the gasometer, and also at a place nearer to the engine.

In the accompanying illustrations, Figs. 275 and 276 represent longitudinal and cross-sectional elevations of the mixing and ignition chambers. Referring to the figures, the gas enters the engine through a $\frac{3}{4}$-inch stop cock, whose pointer handle W rotates over a dial P graduated from zero to 10. When the hand is at zero the cock is closed, and when at 10 it is wide open. When the load is increased and the speed is decreased, the inertia pendulum governor strikes the tappet on the right-hand end of the gas-inlet valve U, causing it to open to an extent that can be regulated by the thimble V. The gas thus enters the space G, and passing through the holes as shown, mixes with atmospheric air, which has come in by way of the $1\frac{1}{2}$-inch air pipe into the air chamber A, whence it, too, passes through numerous small holes so as to cause an intimate commingling of the gas and air in the mixing chamber M.

Once in each two revolutions, a cam on the lay shaft actuates the lever Q, and, through the "inlet-valve lever set screw" S, causes the valve T to rise and so permit the mixture of gas and air, or of air alone, to enter the ignition space B. Here the fresh gases mix with the burnt gases of the preceding stroke, and fill the ignition chamber B, the inlet C, and the combustion chamber and cylinder volume, during the suction stroke of the piston. The passageway D to the hot tube, being, as it were, a dead end, remains filled with the burnt gases of the preceding stroke.

The ignition chamber B is formed in a casting N, bolted to the end of the engine cylinder, so as to have direct communication with it through the rectangular inlet C. On the outside of the ignition-chamber casting N is bolted the casting O, in which is fastened by set screw L the hot-tube tee E, which is connected to the passageway D by a hole $\frac{1}{4}$ inch in diameter. Into the tee E is screwed the hot tube proper X, having a solid end, and

also the lower hot tube *II*, made of $\frac{1}{4}$-inch gas pipe, and having on the end a $\frac{1}{4}$-inch by $\frac{1}{8}$-inch reducer, and the "lower hot-tube pet cock" *I*. This pet cock *I* originally contained a hole $\frac{1}{64}$ inch

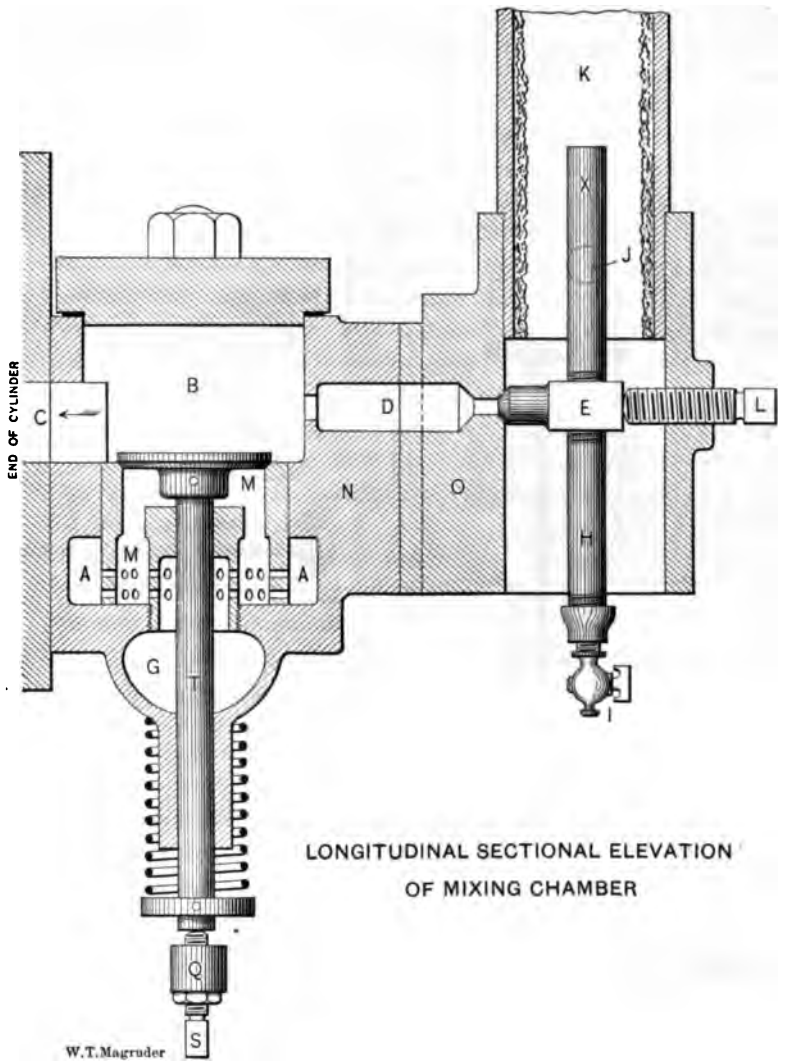


FIG. 275.

in diameter, but was replaced in certain of the experiments by an ordinary $\frac{1}{8}$-inch pet cock. The upper hot tube *X* was surrounded by an asbestos-lined cast-iron chimney *K*, through

which the tip *J* of the Bunsen burner projected, so that the flame could play upon the upper hot tube at a point about 1½ inches above the tee *E*. It will thus be seen that ignition was effected in this mechanism by compressing the burnt gases which were left in the passageway *D*, the tee *E*, and the upper and lower hot tubes *K* and *H*, into the lower hot tube *H*, and

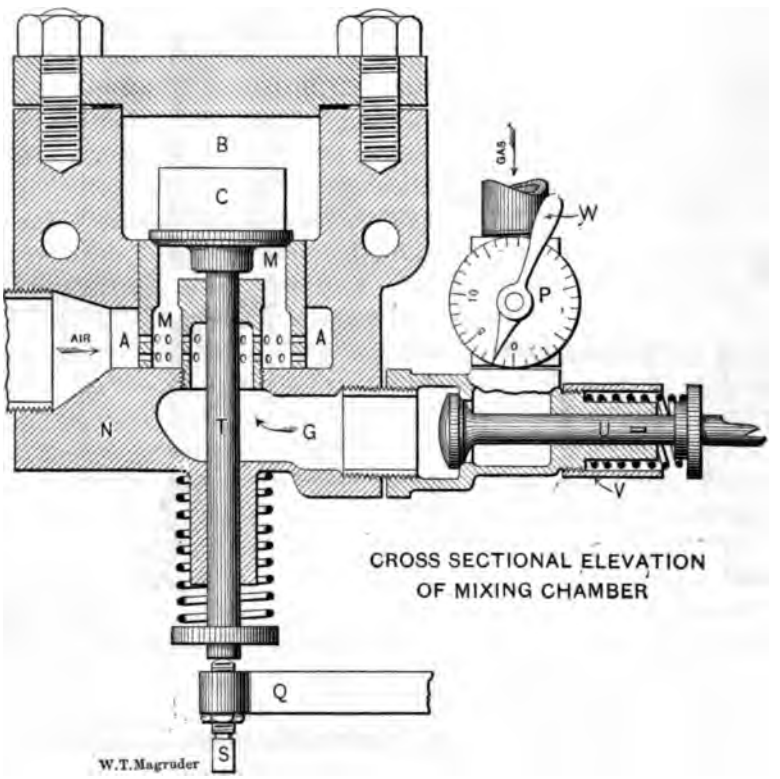


FIG. 276.

the upper portion of the upper hot tube *K*, so that the mixture of fresh gas and air followed and came into contact with that part of the upper hot tube which was red hot, became ignited, and, striking back through tee *E*, passageway *D*, ignition chamber *B*, and inlet *C*, caused the ignition of the large volume of the compressed gas and air in the combustion chamber of the engine, and so caused the piston to make a power stroke.

The exhaust valve was opened by a lever operated through

a roller actuated by a cam on the lay shaft. The roller was journaled on an eccentric stud in the lever, and so arranged that it could be rotated so as to cause the exhaust valve to always remain open a small amount, and, by thus creating a leak at the exhaust valve, decrease the compression and so make the starting of the engine easier. When the tee-handled end of the eccentric was vertical, the exhaust valve was closed and kept closed by its spring; but when the handle was horizontal, the exhaust valve could not close and therefore leaked.

Early in the experimenting with this engine, under the unusual conditions imposed, it was discovered that the time of ignition was a variable depending upon quite a number of different conditions, and that before any accurate and scientific data could be collected or any satisfactory results could be obtained, these conditions must be individually and systematically studied. To do this intelligently, the following schedule of conditions was assigned, and tests made in which, as far as possible, only one condition at a time was allowed to vary.

The variable conditions upon which the time of ignition was assumed to depend were :

1. The length and diameter of the upper hot tube.
2. The length and diameter of the lower hot tube.
3. The volume of the passageway *D*.
4. The amount of compression due to the percentage of piston displacement in clearance volume.
5. A leak at the lower hot-tube pet cock *I*.
6. A leak by the piston rings.
7. The position of the inlet-valve lever set screw.
8. Whether the exhaust valve leaked or not; that is, whether the starting cam handle was vertical or horizontal.
9. The temperature of the jacket-water outlet.
10. The temperature of the mixing and ignition chambers.
11. The speed of the engine at constant jacket-water outlet temperature.
12. The temperature of the hot tube.
13. Whether the previous stroke had been missed or not
14. The pressure of the gas.
15. The position of the gas-cock handle.
16. The size of the air-inlet diaphragm.
17. The pressure, or suction, at which the air was delivered to the engine.

1. *The Length of the Upper Hot Tube.*

From what has previously been said, it is evident that the greater the volumes of the spaces in the upper and lower hot tubes, either or both, the greater will be the amounts of the burnt gases which they will contain, and therefore the sooner will the fresh gases reach the red-hot part of the upper hot tube. Consequently, the longer the upper hot tube, the earlier will be the ignition. Fig. 278, Card No. 8 of Run 136, and Fig. 277, Card No. 20 of Run 139*A*, show this for an upper hot tube 5½ inches long. Fig. 279, Card No. 8 of Run 129, and Fig. 280, Card No. 3 of Run 135, show this for an upper hot tube 4 inches long. Figs. 281 and 282, Cards Nos. 4 and 6 of Run 140, show this for a 3½-inch upper hot tube. Figs. 283 and 284, Cards Nos. 4 and 9 of Run 139*A*, show this for a 2¾-inch hot tube. Figs. 285, 286, and 287, Cards Nos. 2, 7, and 8 of Run 139, show this for a 2-inch hot tube, and also the variation in the time of ignition due to so short a hot tube.

2. *The Length and Diameter of the Lower Hot Tube.*

From what has been said under the first condition, it will be quite apparent that the greater the volume of the lower hot tube (that is, the greater its length for a given diameter, or the greater its diameter for a given length, or both), the earlier will be the time of ignition. This, it is thought, is clearly shown by the diagrams from Run 139*A*, where the length of this tube was changed from 1¼ inches with Fig. 288, Card No. 1, to 2½ inches with Fig. 289, Card No. 2, to 2¾ inches with Figs. 283 and 284, Cards Nos. 4 and 9, and to 8¼ inches with Figs. 290 and 291, Cards Nos. 17 and 18, while the upper hot tube remained constantly 2¾ inches long. Therefore the longer or larger the lower hot tube, the earlier will be the ignition.

3. *The Volume of the Passageway D.*

No means were available to prove this condition, but it would seem quite evident that the larger the volume of the passageway *D* the larger would be the volume of burnt gases for which room would have to be found in the upper or lower hot tubes

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 139A
DATE FEB. 17, 1899 TIME ____M. NO. 20
SPRING 240 LENGTH 2.46 AREA .64 & .42
R.P.M. 280 X.P.M. ____ M.E.P. 62.44 & 40.97
5½" UPPER HOT TUBE 3" LOWER HOT TUBE

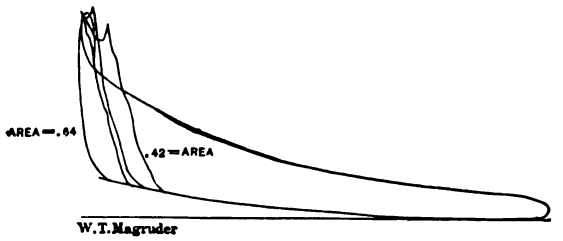


FIG. 277.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 136
DATE NOV. 12, 1898 TIME 11:39 A.M. NO. 8
SPRING 200 LENGTH 2.46 AREA .77 & .66
R.P.M. 290⅓ X.P.M. 42.2 M.E.P. 75.10 & 64.39
1¾" INLET AIR ORIFICE 5½" HOT TUBE

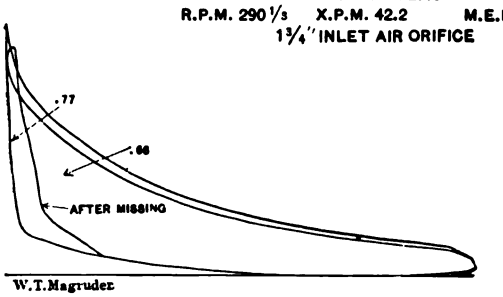


FIG. 278.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 129
DATE NOV. 5, 1898 TIME 10:45 A.M. NO. 8
SPRING 200 LENGTH 2.47 AREA .72
R.P.M. 274⅔ X.P.M. 115 M.E.P. 69.96
1¾" AIR ORIFICE 4" HOT TUBE

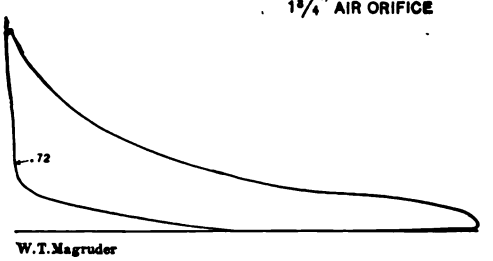


FIG. 279.

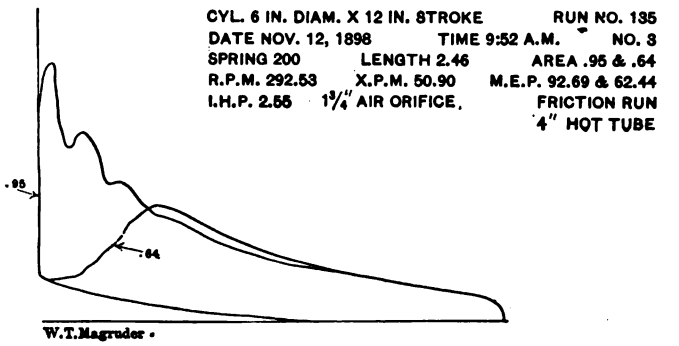


FIG. 280.

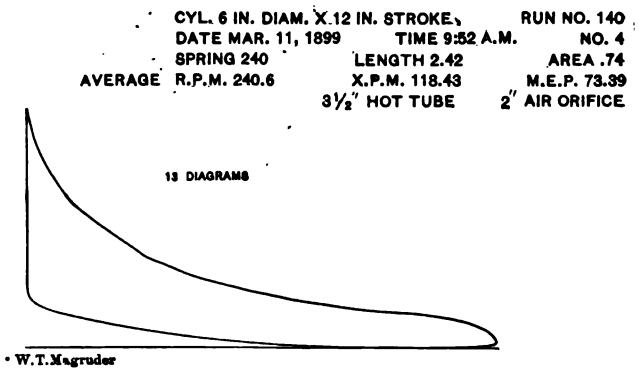


FIG. 281.

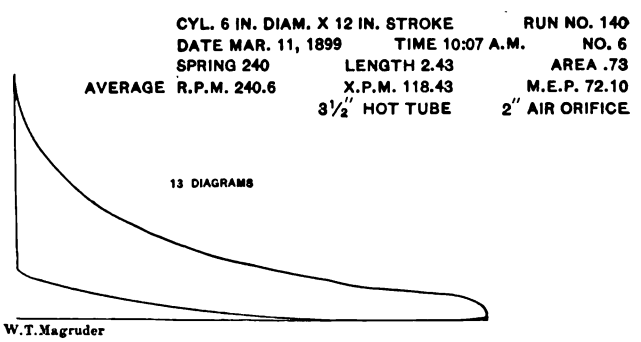


FIG. 282.

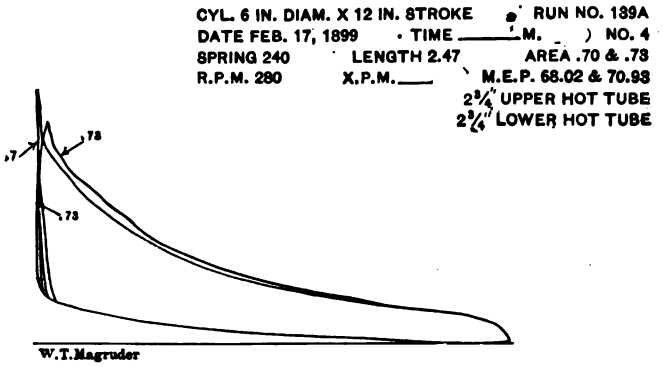


FIG. 283.

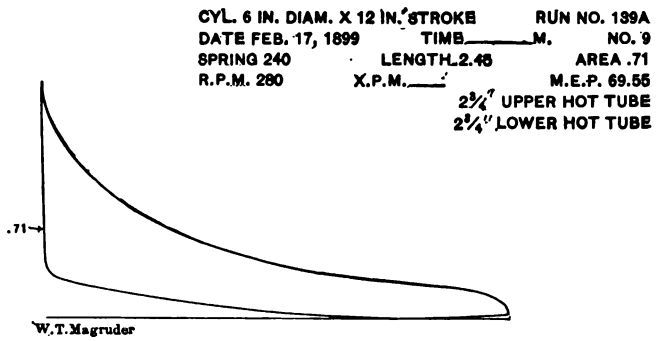


FIG. 284.

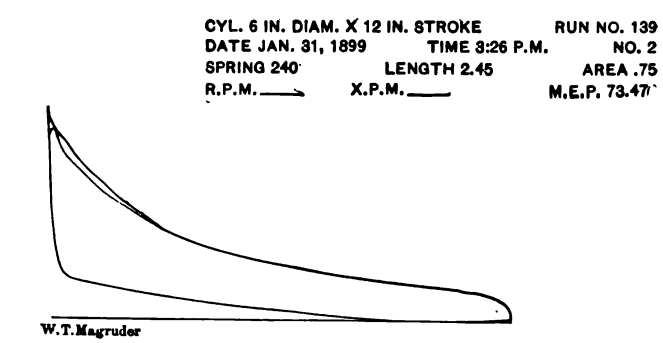


FIG. 285.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 139
DATE JAN. 31, 1899 TIME 3:45 P.M. NO. 7
SPRING 240 LENGTH 2.43 AREA .55 & .50
R.P.M._____ X.P.M._____ M.E.P. 54.32 & 49.38

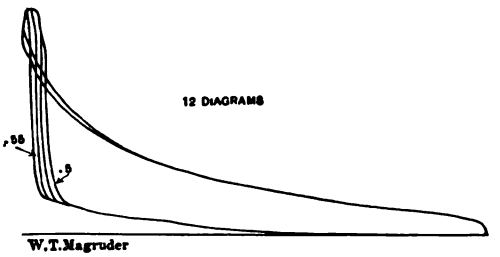


FIG. 286.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 139
DATE JAN. 31, 1899 TIME 3:48 P.M. NO. 8
SPRING 240 LENGTH 2.45 AREA .5
R.P.M._____ X.P.M._____ M.E.P. 48.98

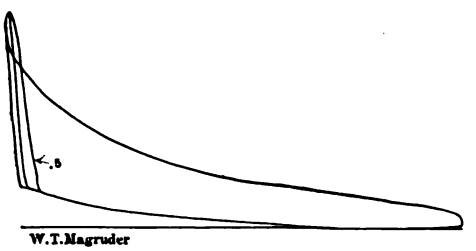


FIG. 287.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 139A
DATE FEB. 17, 1899 TIME_____M. NO. 1
SPRING 240 LENGTH 2.45 AREA .74 & .57
R.P.M. 280 X.P.M._____M.E.P. 72.49 & 55.64
2¾" UPPER HOT TUBE
1¼" LOWER HOT TUBE

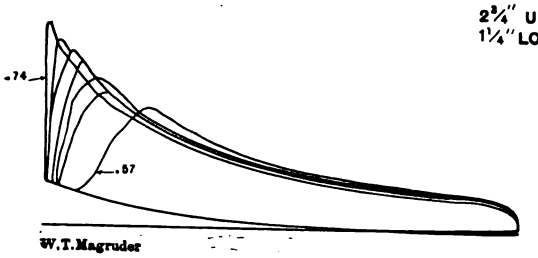


FIG. 288.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 139A
DATE FEB. 17, 1899 TIME ____M. NO. 2
SPRING 240 LENGTH 2.46 AREA .75 & .69
R.P.M. 280 X.P.M. ____ M.E.P. 73.17 & 67.32
2¾" UPPER HOT TUBE
2½ LOWER HOT TUBE

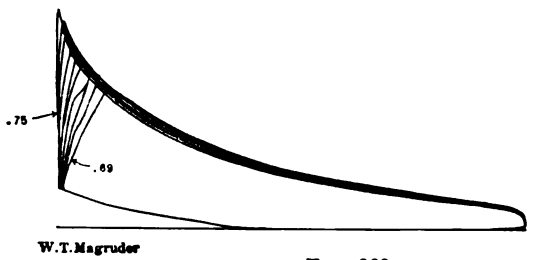


FIG. 289.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 139A
DATE FEB. 17, 1899 TIME ____M. NO. 17
SPRING 240 LENGTH 2.48 AREA .69 & .60
R.P.M. 280 X.P.M. ____ M.E.P. 58.06 & 66.78
2¾" UPPER HOT TUBE
8¼" LOWER HOT TUBE

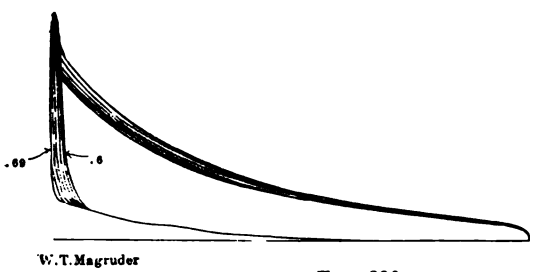


FIG. 290.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 139A
DATE FEB. 17, 1899 TIME ____M. NO. 18
SPRING 240 LENGTH 2.44 AREA .62 & .57
R.P.M. 280 X.P.M. ____ M.E.P. 60.98 & 56.06
2¾" UPPER HOT TUBE
8¼" LOWER HOT TUBE

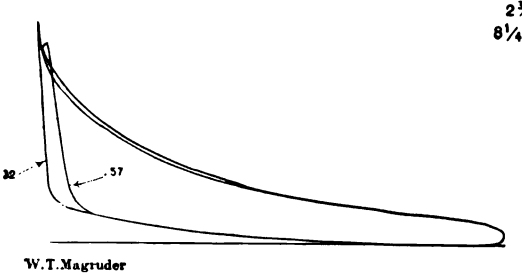


FIG. 291.

before the fresh gases could become ignited. The logical conclusion would therefore seem to be that the larger the passageway *D*, the later would be the ignition.

4. *The Amount of Compression Due to the Percentage of Piston Displacement in Clearance Volume.*

With this engine no facilities were available for either increasing or decreasing the volume of the combustion chamber, and thereby changing the percentage of clearance volume, which was 33.99 per cent. of the piston displacement. But it is evident that with a larger combustion chamber the compression will be lower, and the volume into which the burnt gases of the passageway *D*, etc., will be compressed will be larger, and, therefore, the greater the clearance volume and the lower the compression, the later will be the ignition, and *vice versa*.

5. *A Leak at the Lower Hot-tube Pet Cock I.*

From Figs. 292, 293, 294, 295, 296, and 297, Cards Nos. 3, 6, 14, 18, 22, and 27 of Run 156, it is evident that a leak at the lower hot-tube pet cock (or at where the tubes *H* and *X* are screwed into the tee *E*) will allow the burnt gases in the passageway *D* to be exhausted into the air, and thereby cause a very early ignition.

6. *A Leak by the Piston Rings.*

Run 159 was made to determine the result of running without the four piston rings being in their usual places. The leak of burnt gases from the front end of the cylinder was very perceptible. The compression was reduced from the usual 60 pounds to about 48 pounds, and the average mean effective pressure was reduced from 75 or 80 pounds to 48 pounds, except after missing a stroke. Figs. 298, 299, and 300, Cards Nos. 2, 3, and 5 of Run 159, show that ignition took place exactly on the dead centre with a hot tube 3½ inches long. It would therefore seem that the omission or breakage of one or more piston rings, while effecting the compression, mean effective pressure, and the indicated horse-power, will have practically but little effect upon the time of ignition.

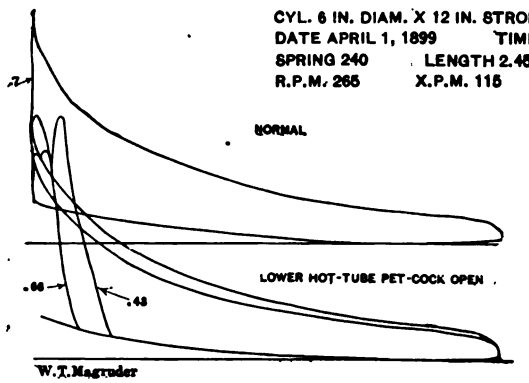


FIG. 292.

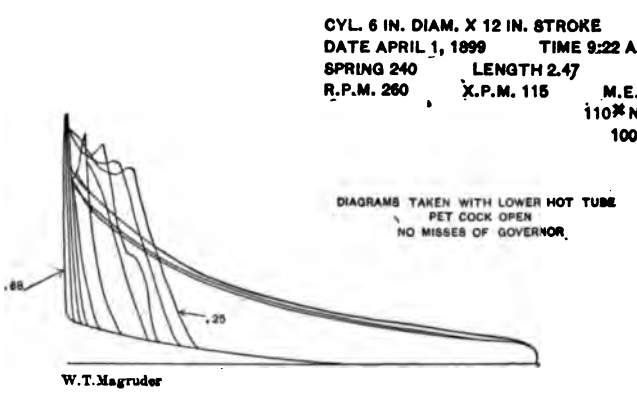


FIG. 293.

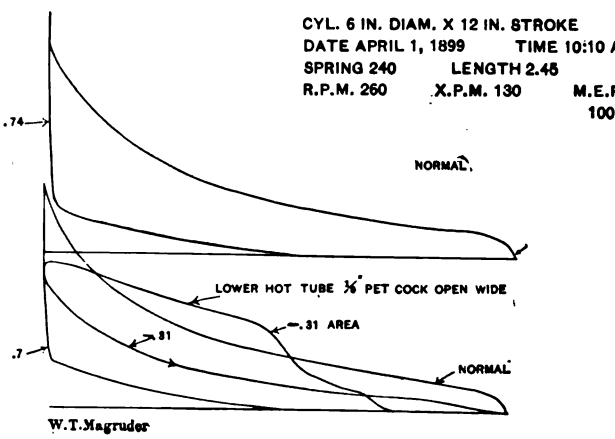


FIG. 294.

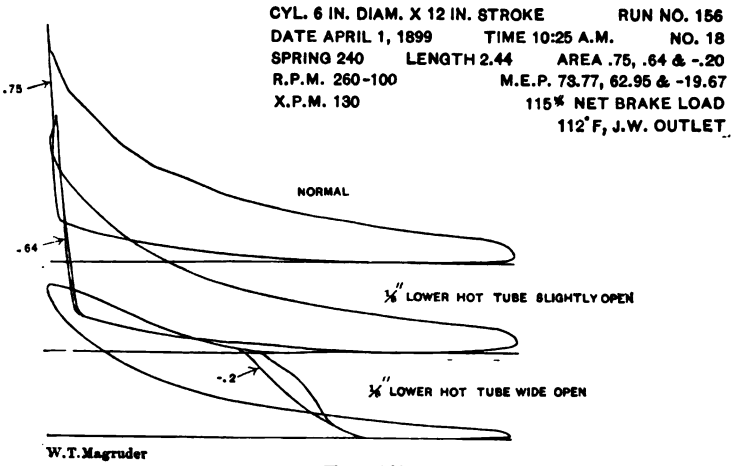


FIG. 295.

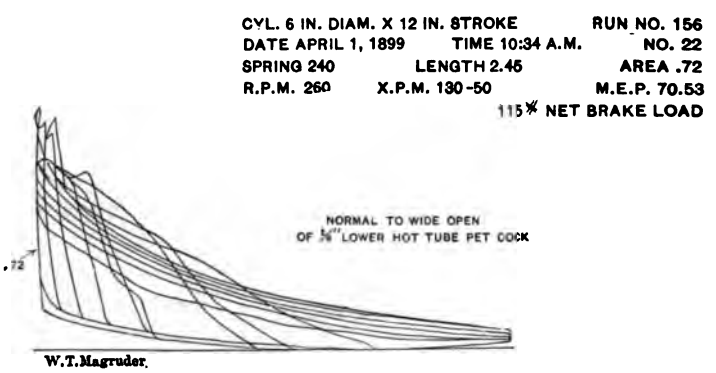


FIG. 296.

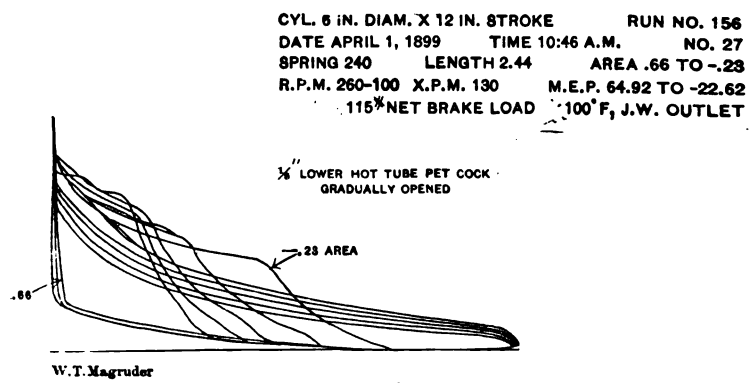


FIG. 297.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 159
DATE APRIL 5, 1899 TIME 2:31 P.M. NO. 2
SPRING 240 LENGTH 2.45 AREA .52 TO .35
R.P.M. 260 X.P.M. 120 M.E.P. 50.94 TO 34.29
3½" HOT TUBE

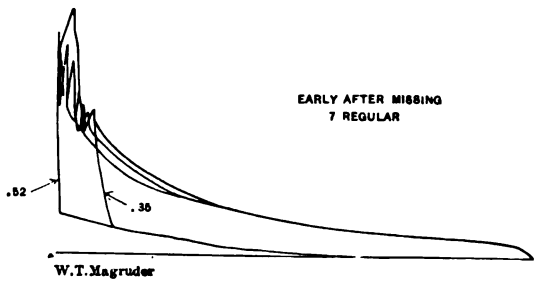


FIG. 298.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 159
DATE APRIL 5, 1899 TIME 2:32 P.M. NO. 3
SPRING 240 LENGTH 2.45 AREA .55 TO .47
R.P.M. 260 X.P.M. 120 M.E.P. 53.88 TO 46.04
3½" HOT TUBE

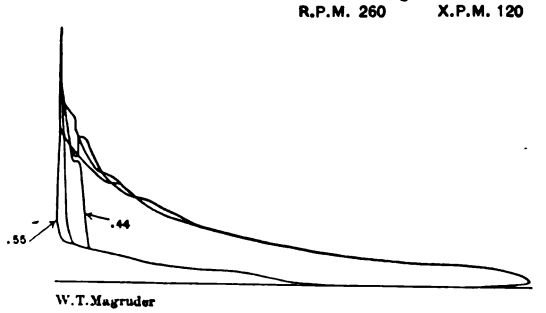


FIG. 299.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 159
DATE APRIL 5, 1899 TIME 2:34 P.M. NO. 5
SPRING 240 LENGTH 2.47 AREA .46
R.P.M. 260 X.P.M. 120 M.E.P. 44.70
3½" HOT TUBE

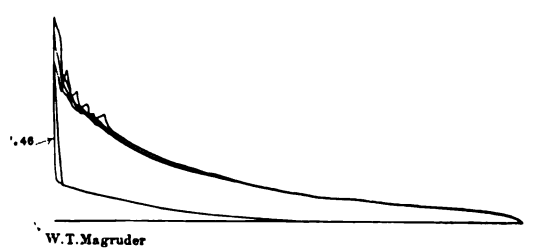


FIG. 300.

7. *The Position of the Inlet-valve Lever Set Screw S.*

This set screw *S* caused the inlet valve to open at the beginning of the suction stroke. The spiral spring surrounding the spindle of the valve caused the valve to seat itself as soon as the motion of the set screw would permit. By lowering the set screw, it is evident that the valve was opened later and closed earlier, and the result on the engine was a decrease in speed. By raising the screw, thereby preventing the valve from spring-seating, the ignition was made much later and the speed of the engine decreased from 266 revolutions per minute to 200 revolutions per minute. On these cards, the word "normal" refers to the diagram which was taken under normal conditions, either just before or after making the special diagram, and was taken to make the comparison more marked. Figs. 301 and 302, Cards Nos. 7 and 10 of Run 146, show the effect of turning down the inlet-valve lever set screw, while Fig. 303, Card No. 6 of the same run, shows the effect of turning it up on the time of ignition and the areas of the cards. When turned up one turn, the inlet valve was never allowed to tightly close.

8. *Whether the Exhaust Valve Leaked or Not.*

Figs. 304, 305, and 306, Cards Nos. 1, 2, and 4 of Run 150, show that the ignition was later when the handle was horizontal than when it was vertical, and that the effect of causing the exhaust valve to remain open even a slight amount during the entire stroke was to reduce the average mean effective pressure from 72.68 pounds, when the handle was vertical, to 62.175 pounds, when the handle was horizontal. The conclusion therefore is that any leaks about the inlet or outlet valves cause the ignition to take place later.

9. *The Temperature of the Jacket-water Outlet.*

Figs. 307 to 312, the cards of Run 149, would seem to indicate that at constant speed the higher the temperature of the jacket-water outlet the earlier is the ignition; but that with constant and excessive load, so that the governor hit every time and did not miss an ignition, the speed of the engine increased from about 180 revolutions per minute to 280 revolutions per minute as the temperature of the jacket-water outlet increased from 60

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 146
DATE MAR. 14, 1899 TIME 4:41 P.M. NO. 7
SPRING 240 LENGTH 2.44 AREA .78 TO .73
R.P.M. 266 X.P.M. 129 M.E.P. 76.72 TO 71.80

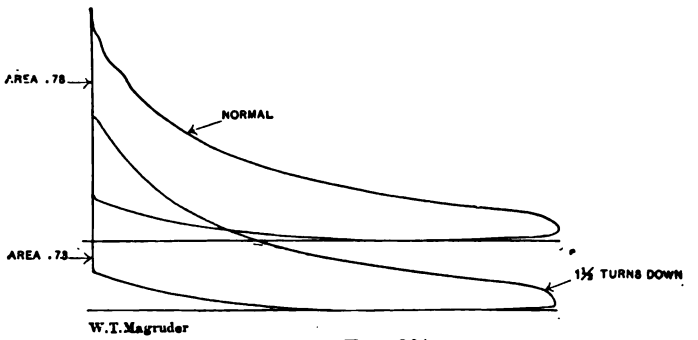


FIG. 301.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 146
DATE MAR. 14, 1899 TIME 4:46 P.M. NO. 10
SPRING 240 LENGTH 2.46 AREA .76 TO .64
R.P.M. 266 X.P.M. 129 M.E.P. 74.15 TO 62.44

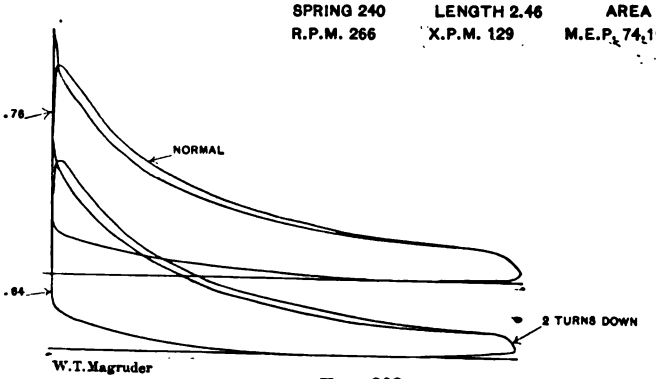


FIG. 302.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 146
DATE MAR. 14, 1899 TIME 4:38 P.M. NO. 6
SPRING 240 LENGTH 2.45 AREA .74 TO .64
R.P.M. 266 X.P.M. 129 M.E.P. 72.49 TO 62.69

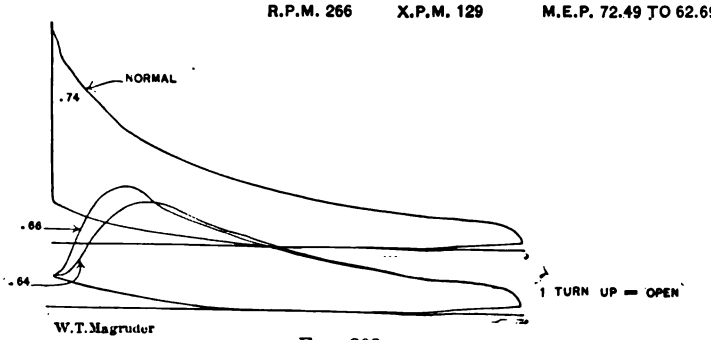


FIG. 303.

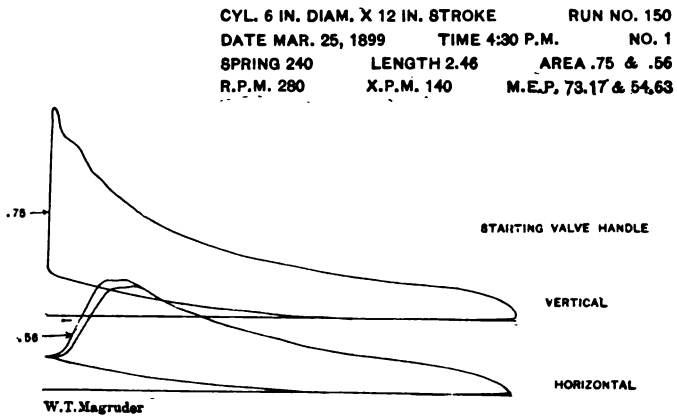


FIG. 304.

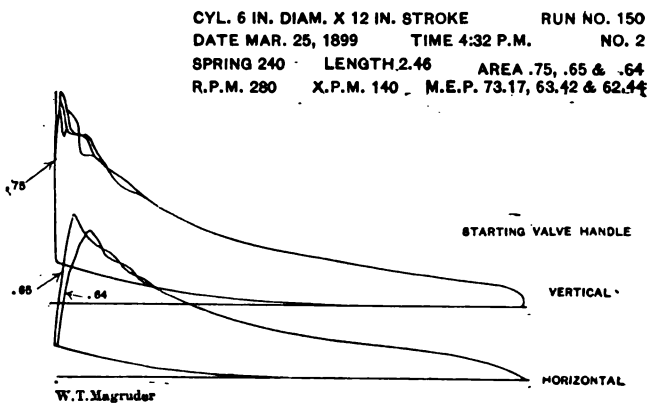


FIG. 305.

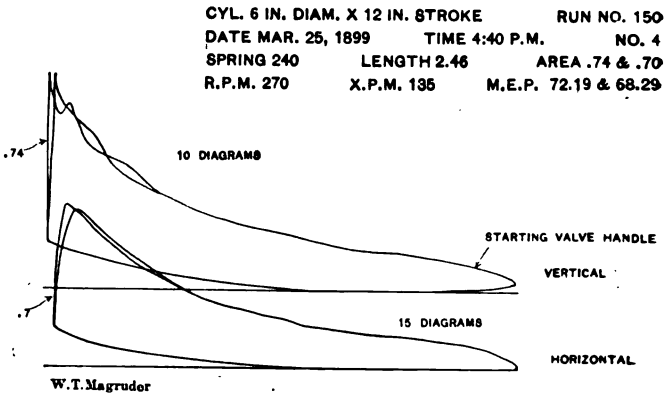


FIG. 306.

CYL. 6 IN. DIAM. X 12 IN. STROKE — RUN NO. 149
DATE MAR. 21, 1899 — TIME 4:17 P.M. — NO. 1
SPRING 240 — LENGTH 2.45 — AREA .68
R.P.M. 180 — X.P.M. — M.E.P. 66.61
GAS COCK AT 10 — 60° F, J.W. OUTLET
2" AIR INLET

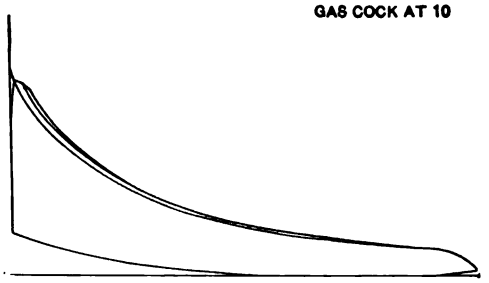


FIG. 307.

CYL. 6 IN. DIAM. X 12 IN. STROKE — RUN NO. 149
DATE MAR. 21, 1899 — TIME 4:34 P.M. — NO. 10
SPRING 240 — LENGTH 2.44 — AREA .65
R.P.M. 212 — X.P.M. 106 — M.E.P. 63.94
GAS COCK AT 10 — 120° F, J.W. OUTLET
2" AIR INLET

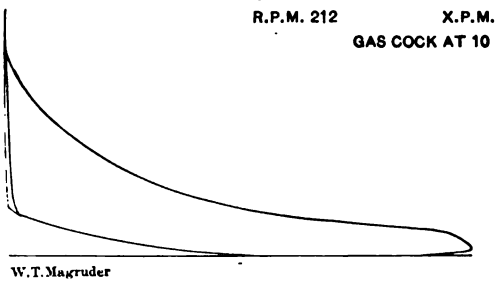


FIG. 308.

CYL. 6 IN. DIAM. X 12 IN. STROKE — RUN NO. 149
DATE MAR. 21, 1899 — TIME 4:51 P.M. — NO. 17
SPRING 240 — LENGTH 2.46 — AREA .6
R.P.M. 240 — X.P.M. 120. — M.E.P. 58.54
GAS COCK AT 10 — 174° F, J.W. OUTLET
2" AIR INLET

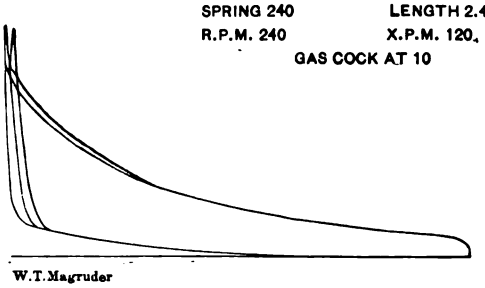


FIG. 309.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 149
DATE MAR. 21, 1899 TIME 5:09 P.M. NO. 26
SPRING 240 LENGTH 2.44 AREA .65
R.P.M. 280 X.P.M. 140 M.E.P. 63.94
170°F, J.W. OUTLET

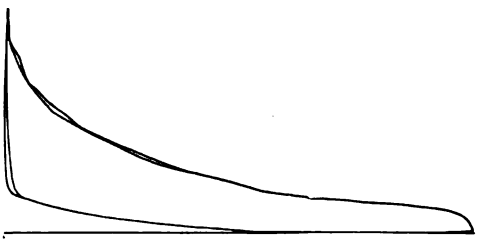


FIG. 310.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 149
DATE MAR. 21, 1899 TIME 4:56 P.M. NO. 20
SPRING 240 LENGTH 2.45 AREA .69
R.P.M. 268 X.P.M. 134 M.E.P. 67.59
120# NET BRAKE LOAD
X GAS 832°F. 192°F, J.W. OUTLET

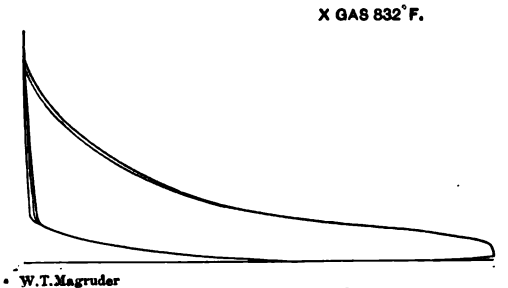


FIG. 311.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 149
DATE MAR. 21, 1899 TIME 5:00 P.M. NO. 23
SPRING 240 LENGTH 2.44 AREA .65
R.P.M. 264 X.P.M. 132 M.E.P. 63.94
X GAS 840°F. 205°F, J.W. OUTLET

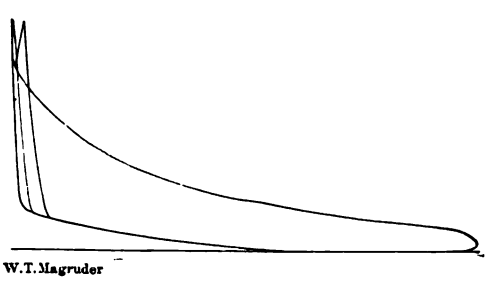


FIG. 312.

degrees Fahr. to 200 degrees Fahr., the inlet temperature being 49 degrees. With this highest outlet temperature, the amount of water circulating was so small and the valves were so nearly closed that any slight change in the water pressure, so as to produce a corresponding change in the quantity of water circulating, caused a marked decrease in speed.

10. *The Temperature of the Mixing and Ignition Chambers.*

Figs. 313, 314, 315, and 316, Cards Nos. 2, 3, 4, and 5 of Run 139 *BBB*, illustrate how the time of ignition gets earlier as the engine gets hotter, the speed and jacket-water temperatures remaining constant.

11. *The Speed of the Engine at Constant Jacket-water Outlet Temperature.*

Fig. 317, Card No. 30 of Run 148, shows that the time of ignition is earlier with the slower speeds, and that above 275 revolutions per minute with this engine, no change in time of ignition could be discovered. This latter result was probably due to a small change of crank circle arc at the dead centre not being easily calculated when measured by its diametral projection.

12. *The Temperature of the Hot Tube.*

It is self-evident that the hotter the hot tube, the more quickly will the gases be heated up and become inflamed, and therefore the earlier will be the ignition, and vice versa. Fig. 318, Card No. — of Run 139*AA*, illustrates the effect of a change in the temperature of the hot tube by a series of diagrams of consecutive ignitions, showing that the cooler the hot tube the later was the ignition. It should also be noted that each ignition curve starts from a different point on the compression line, and that the expansion lines and terminal pressures were higher the later was the ignition.

13. *Whether the Previous Stroke had been Missed or Not.*

Figs. 319 and 320, Cards Nos. 1 and 10 of Run 129; Fig. 321, Card No. 7 of Run 131; Fig. 322, Card No. 2 of Run 144; Figs. 323 and 324, Cards Nos. 6 and 7 of Run 155, illustrate the fact that, with a four-cycle engine with a hit-or-miss governor, and taking

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 139BBB
DATE FEB. 21, 1899 TIME 3:07 P.M. NO. 2
SPRING 240 LENGTH 2.45 AREA .85 TO .56
R.P.M. 280 X.P.M._____ M.E.P. 83.26 TO 54.86
2½" UPPER HOT TUBE
2½" LOWER HOT TUBE 120# NET BRAKE LOAD

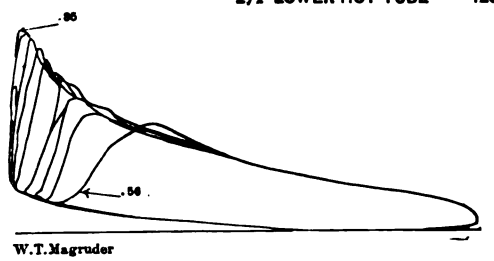


FIG. 313.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 139BBB
DATE FEB. 21, 1899 TIME 3:10 P.M. NO. 3
SPRING 240 LENGTH 2.45 AREA .75 TO .70
R.P.M. 280 X.P.M. ___ M.E.P. 73.47 TO 68.57
2½" UPPER HOT TUBE
2½" LOWER HOT TUBE 120# NET BRAKE LOAD

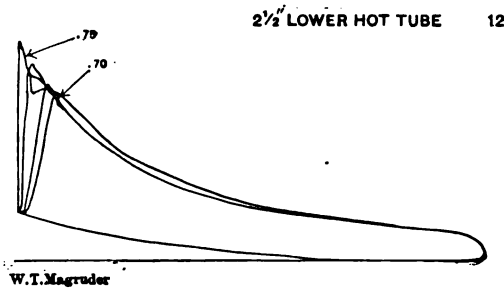


FIG. 314.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 139BBB
DATE FEB. 21, 1899 TIME 3:11 P.M. NO. 4
SPRING 240 LENGTH 2.45 AREA .78 TO .70
R.P.M. 280 X.P.M.___ M.E.P. 76.41 TO 68.57
2½" UPPER HOT TUBE
2½" LOWER HOT TUBE 110# NET BRAKE LOAD

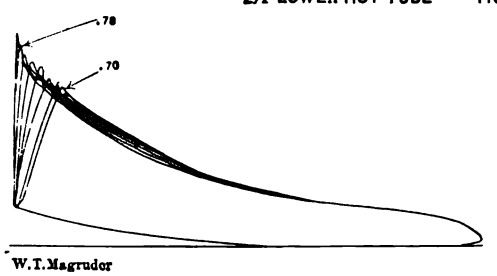


FIG. 315.

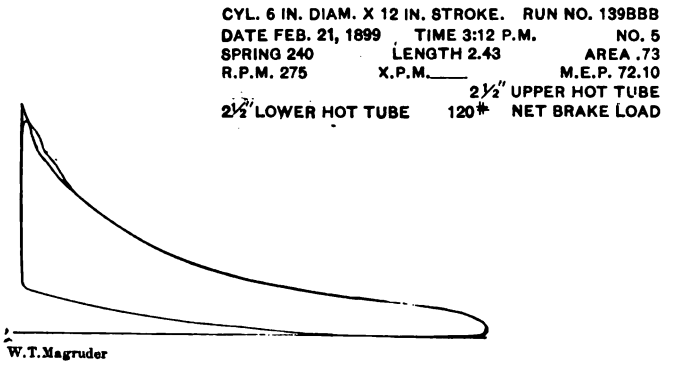


FIG. 316.

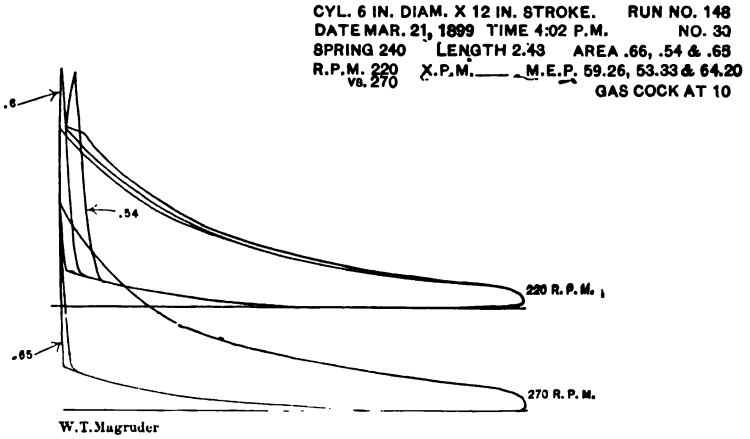


FIG. 317.

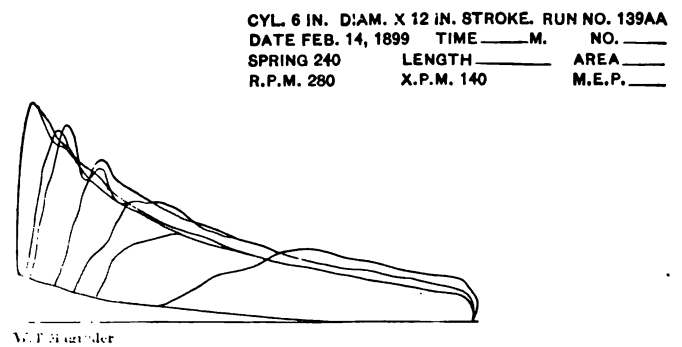


FIG. 318.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 129
DATE . NOV. 5, 1898 TIME 10:28 A.M. NO. 1
SPRING 200 LENGTH 2.46 AREA .74 & .66
R.P.M. 274⅔ X.P.M. 115 M.E.P. 72.20 & 64.39
1¾" AIR ORIFICE 4" HOT TUBE

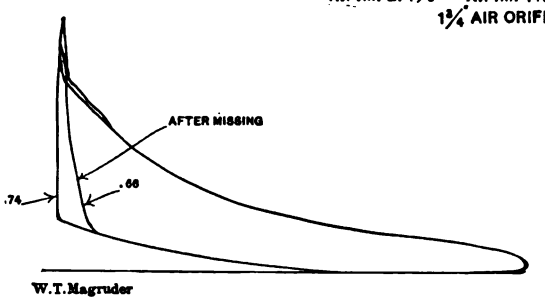


FIG. 319.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 129
DATE NOV. 5, 1898 TIME 10:52 A.M. NO. 10
SPRING 200 LENGTH 2.45 AREA .64 & .56
R.P.M. 274⅔ X.P.M. 115 M.E.P. 62.69 & 56.82
1¾" AIR ORIFICE 4" HOT TUBE

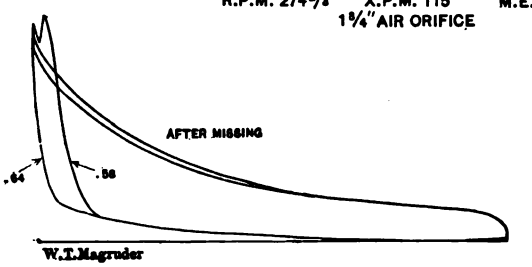


FIG. 320.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 131
DATE NOV. 5, 1898 TIME 11:32 A.M. NO. 7
SPRING 200 LENGTH 2.45 AREA .73 & .64
R.P.M. 268.93 X.P.M. 125.27 M.E.P. 71.51 & 62.69
2" AIR ORIFICE 4" HOT TUBE

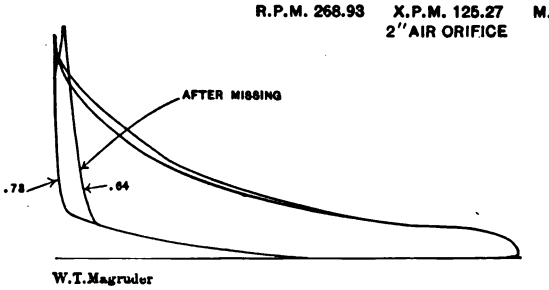


FIG. 321.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 144
DATE MAR. 14, 1899 TIME 3:49 P.M. NO. 2
SPRING 240 LENGTH 2.46 AREA .73 & .54
R.P.M. 268 X.P.M. 132 M.E.P. 71.22 & 52.68
3½" HOT TUBE

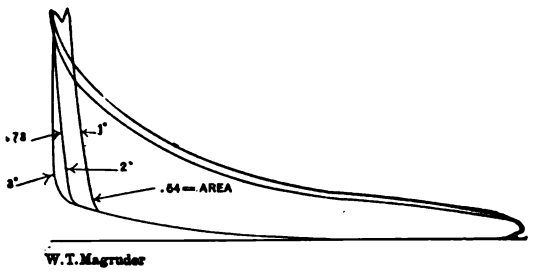


FIG. 322.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 155
DATE APR. 1, 1899 TIME 8:36 A.M. NO. 6
SPRING 240 LENGTH 2.45 AREA .83 & .78
R.P.M. 260 X.P.M. 115 M.E.P. 81.31 TO 76.41

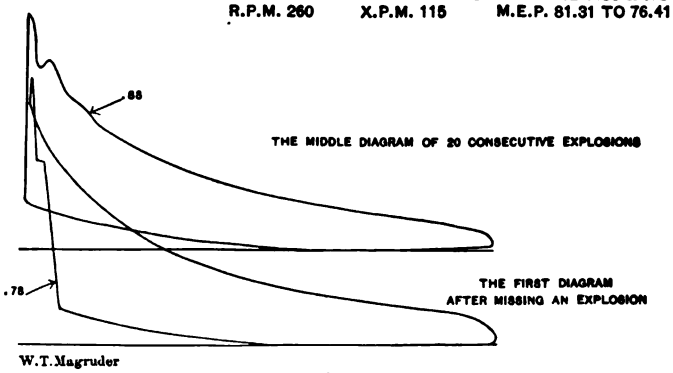


FIG. 323.

CYL. 6 IN. DIAM. X 12 IN. STROKE. RUN NO. 155
DATE APR. 1, 1899 TIME 8:41 A.M. NO. 7
SPRING 240 LENGTH 2.45 AREA .80 TO .77
R.P.M. 268 X.P.M. 115 M.E.P. 78.365 TO 75.43
120# NET BRAKE LOAD

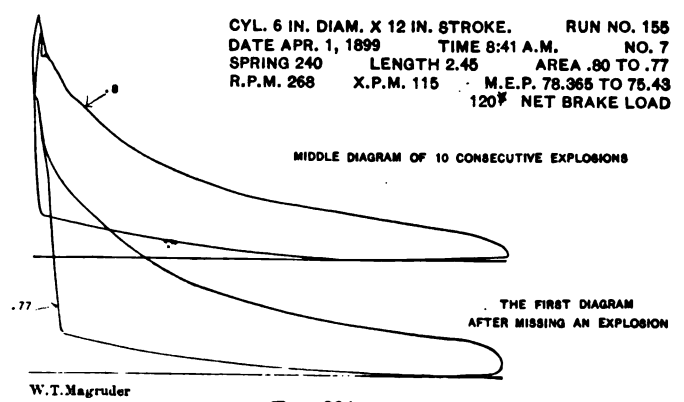


FIG. 324.

air every other revolution, the time of ignition is earlier after an ignition has been missed and the burnt gases have been scavenged by fresh air. These cards also show why it is that the gas consumption per indicated horse-power per hour is so much greater with frictional or light loads than with heavy loads.

It is shown in Fig. 325, Card No. 13 of Run 133, that, when using an air-inlet orifice as small as 1 inch in diameter, the diagram obtained after missing, even with the earlier ignition incident thereto, really produces more power on account of its larger supply of air than the succeeding charges with later ignition and a single supply of air.

14. *The Pressure of the Gas.*

Figs. 326 to 330, Cards Nos. 1, 2, 3, 4, and 5 of Run 127*B*, show that, with a constant quantity of air coming through a 1½-inch air-inlet diaphragm, the time of ignition was earlier with 3-inch gas pressure than with either more or less gas pressure—that is, that the mixture so produced was more inflammable; but that the card with 8-inch gas pressure gave the greatest mean effective pressure.

15. *The Position of the Gas-cock Handle.*

Figs. 331, 332, and 333, Cards Nos. 2, 3, and 8 of Run No. 145, show that, by changing the gas-cock handle from the wide-open position marked "10" to the positions marked "7," "6," and "5," respectively, the ignition was made earlier; that the areas of the diagrams, and therefore the mean effective pressures, decreased correspondingly; and that from a speed of 264 revolutions per minute with the gas cock at 10, the speed of the engine decreased to about 240 if the gas cock was changed to 7.

The conclusion therefore is that with less gas, for the given amount of air, the earlier is the ignition, within certain limits. Possibly, if later ignition could be secured—by shortening the hot tube, for example—the engine would give more power per cubic foot of gas used.

16. *The Size of the Air-inlet Diaphragm.*

Figs. 334 to 337, Cards Nos. 9, 10, 12, and 34 of Run 148, show the effect of changing the air-inlet diaphragm from 1¾-inch diameter to 1½-inch, to 1¼-inch, and finally to 1-inch, as compared with cards obtained when there was no diaphragm in the

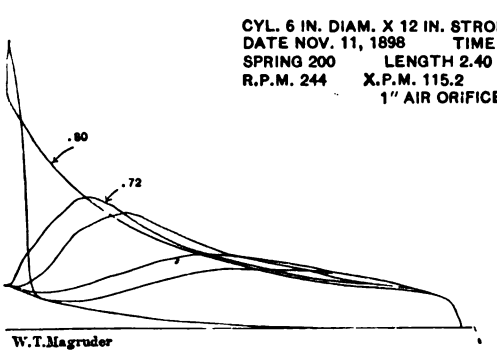


FIG. 325.

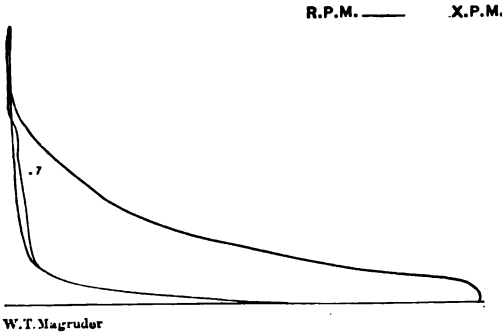


FIG. 326.

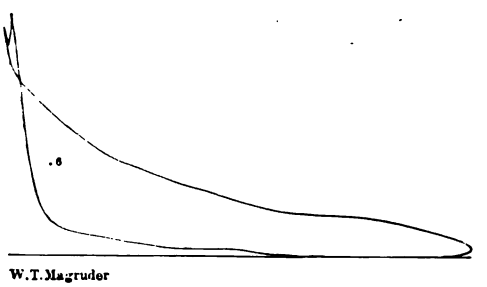


FIG. 327.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 127B
DATE NOV. 5, 1898 TIME ____ M. NO. 3
SPRING 200 LENGTH 2.45 AREA .55
R.P.M. ____ X.P.M. ____ M.E.P. 53.88
1½" INLET AIR ORIFICE
3" GAS PRESSURE

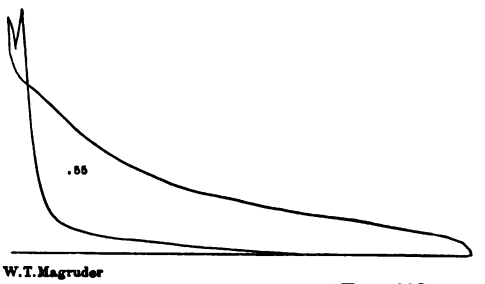


FIG. 328.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 127B
DATE NOV. 5, 1898 TIME ____ M. NO. 4
SPRING 200 LENGTH 2.45 AREA .65
R.P.M. ____ X.P.M. ____ M.E.P. 62.67
1½" AIR ORIFICE
6" GAS PRESSURE

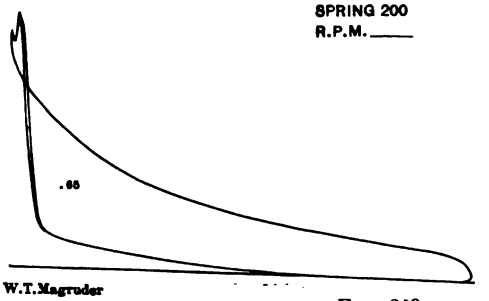


FIG. 329.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 127B
DATE NOV. 5, 1898 TIME ____ M. NO. 5
SPRING 200 LENGTH 2.45 AREA .75
R.P.M. ____ X.P.M. ____ M.E.P. 73.47
1½" AIR ORIFICE
8" GAS PRESSURE

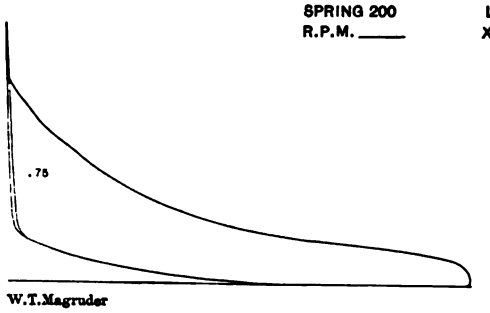


FIG. 330.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 145
DATE MAR. 14, 1899 TIME 4:08 P.M. NO. 2
SPRING 240 LENGTH 2.45 AREA .74 & .59
R.P.M. 264 X.P.M. 129 M.E.P. 72.49 & 57.80

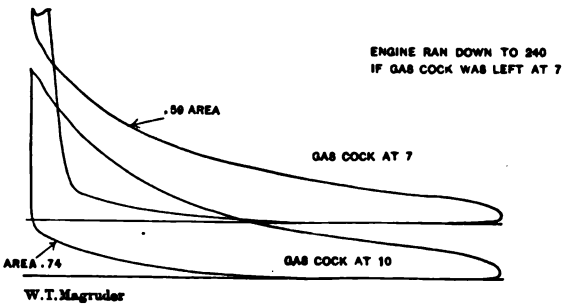


FIG. 331.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 145
DATE MAR. 14, 1899 TIME 4:12 P.M. NO. 3
SPRING 240 LENGTH 2.46 AREA .80 & .64
R.P.M. 264, 270 X.P.M. 129, 131 M.E.P. 78.05 & 62.44

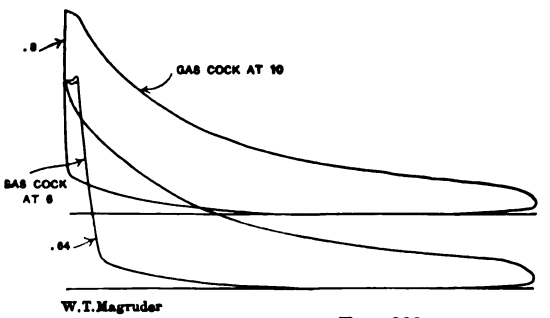


FIG. 332.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 145
DATE MAR. 14, 1899 TIME 4:24 P.M. NO. 8
SPRING 240 LENGTH 2.46 AREA .73 TO .60 TO .50
R.P.M. 268 X.P.M. 134 M.E.P. 71.22, 58.74 & 48.78

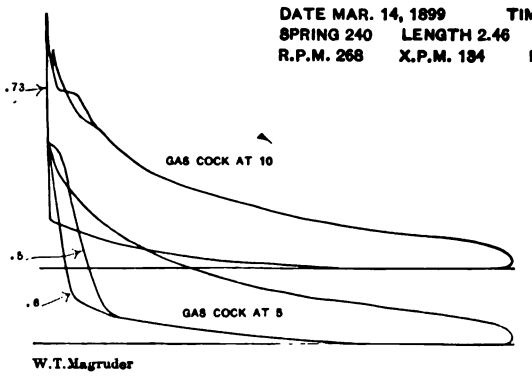


FIG. 333.

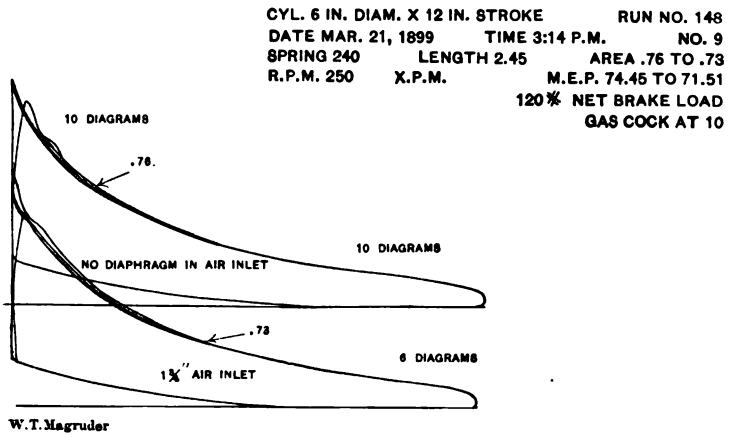


FIG. 334.

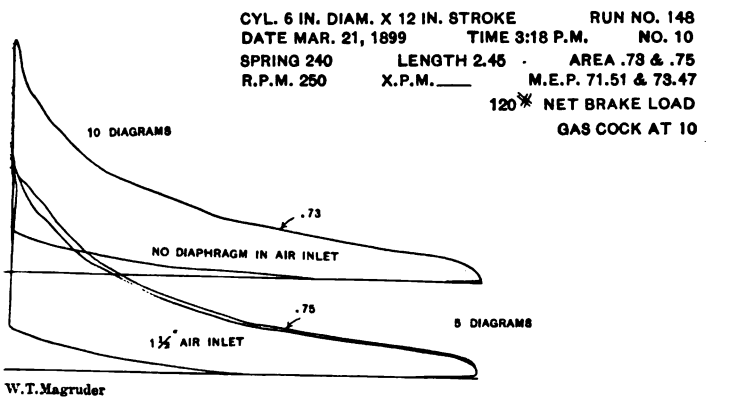


FIG. 335.

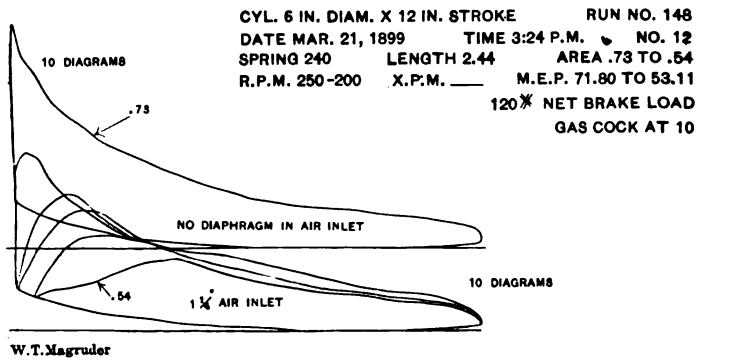
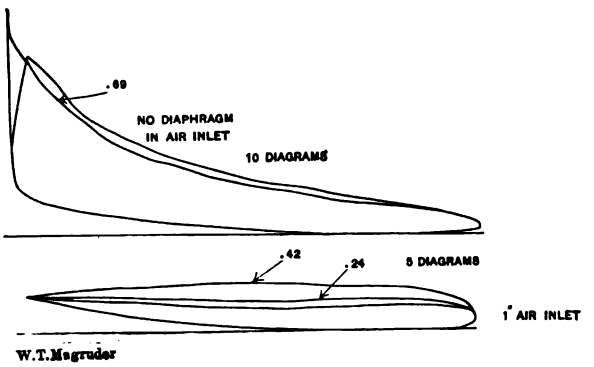


FIG. 336.

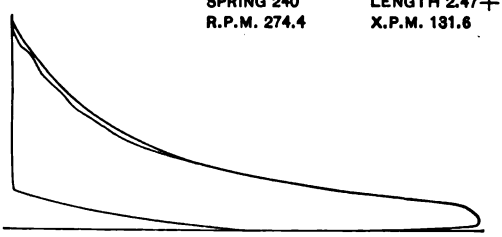
CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 148
DATE MAR. 21, 1899 TIME 4:11 P.M. NO. 34
SPRING 240 LENGTH 2.43 AREA .69 TO .42 TO .24
R.P.M. 235 X.P.M. ___ M.E.P. 68.15 TO 41.48 TO 23.70
GAS COCK AT 10



W.T.Magruder

FIG. 337.

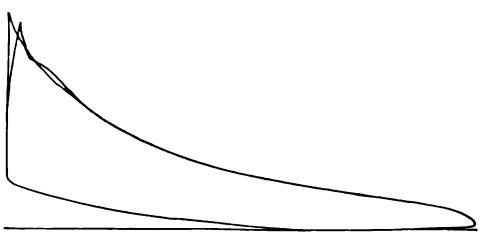
CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 160
DATE APRIL 18, 1899 TIME 3:19 P.M. NO. 2
SPRING 240 LENGTH 2.47+ AREA .85
R.P.M. 274.4 X.P.M. 131.6 M.E.P. 82.59



W.T.Magruder

FIG. 338.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 160
DATE APRIL 18, 1899 TIME 3:35 P.M. NO. 5
SPRING 240 LENGTH 2.46 AREA .78
R.P.M. 274.4 X.P.M. 131.6 M.E.P. 76.10



W.T.Magruder

FIG. 339.

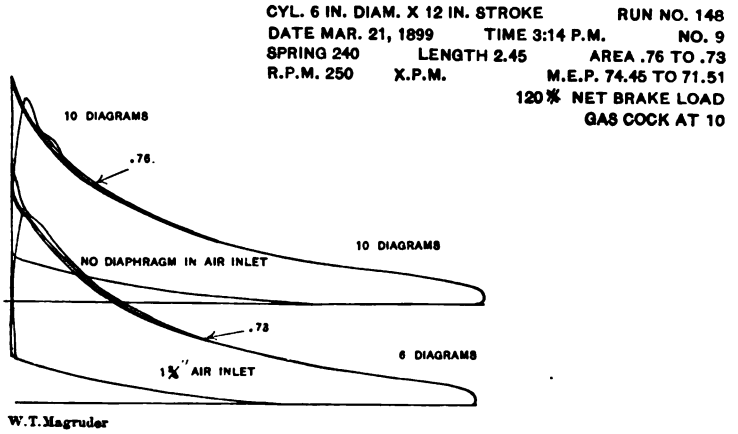


FIG. 334.

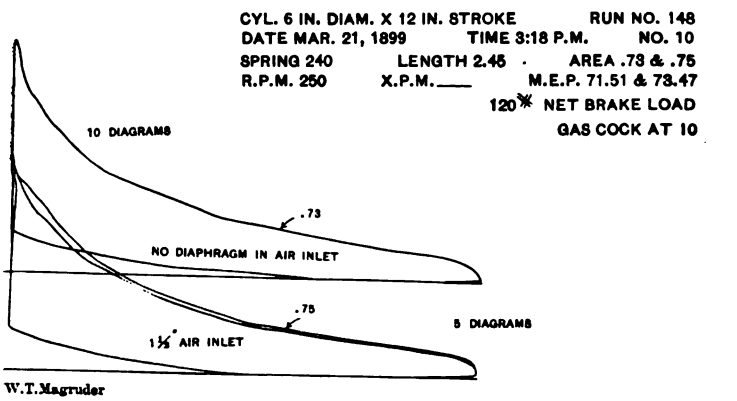


FIG. 335.

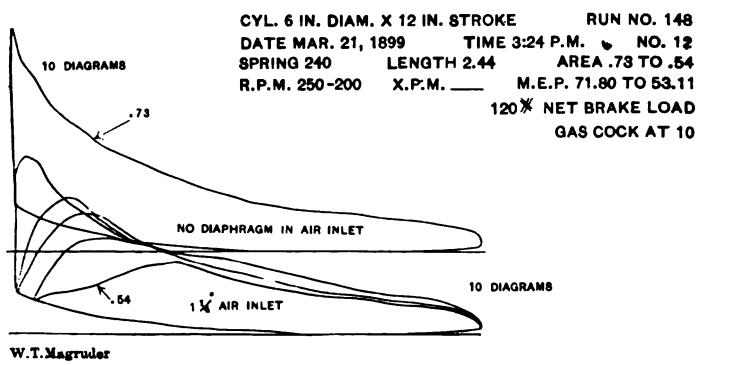


FIG. 336.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 148
DATE MAR. 21, 1899 TIME 4:11 P.M. NO. 34
SPRING 240 LENGTH 2.43 AREA .69 TO .42 TO .24
R.P.M. 235 X.P.M. ___ M.E.P. 68.15 TO 41.48 TO 23.70
GAS COCK AT 10

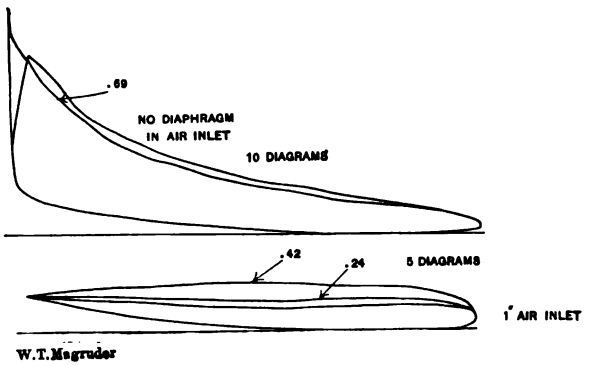


FIG. 337.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 160
DATE APRIL 18, 1899 TIME 3:19 P.M. NO. 2
SPRING 240 LENGTH 2.47+ AREA .85
R.P.M. 274.4 X.P.M. 131.6 M.E.P. 82.59

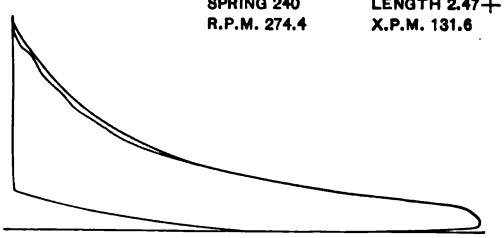


FIG. 338.

CYL. 6 IN. DIAM. X 12 IN. STROKE RUN NO. 160
DATE APRIL 18, 1899 TIME 3:35 P.M. NO. 5
SPRING 240 LENGTH 2.46 AREA .78
R.P.M. 274.4 X.P.M. 131.6 M.E.P. 76.10

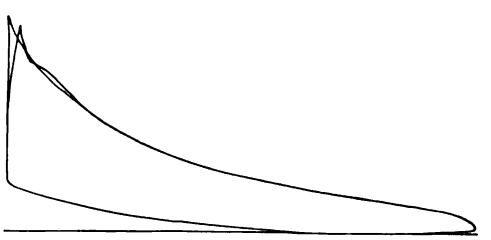


FIG. 339.

2-inch union in the air-inlet pipe, and the gas cock being wide open in all cases. The conclusion therefore is that with the gas cock wide open, to throttle the air supply caused the ignition to be later.

17. *The Pressure, or Suction, with which the Air was Delivered to the Engine.*

In certain of the 25 preliminary tests previously referred to, in order to vary the ratio of air to gas as much as possible, the air was either forced by a pressure-blower, or else sucked by the engine, first through an air meter, and then through a 6-inch galvanized iron pipe, to the 2-inch air-inlet union at the engine. A valve at the inlet to the meter enabled the desired suction or pressure to be obtained. The results then obtained confirm the results recorded in cases Nos. 14, 15, and 16, above, namely, that, within limits, the greater the air pressure the earlier is the ignition, and also that the greater the air suction the later is the ignition; in other words, that if the mixture be a lean one, the ignition is earlier; whereas if the mixture be a rich one, the ignition is later. In either case, the mean effective pressures of the diagrams and therefore the indicated horse-powers are less, and the consumption of gas per indicated horse-power per hour will be greater, than if the ratio is such as to give the proper mixture to insure proper timing of the ignition and the best combustion of the gas. By a "lean mixture" is here meant one in which the volumes of gas and air used are as one to eight; and by a "rich mixture," one in which the ratio is as one to four.

Lest the impression should be created that the irregular cards here presented are the usual thing with this engine, Figs. 338 and 339, Cards Nos. 2 and 5 of Run 160, are added as fair samples of a very regular set of cards, and the following are the average results of the 30-minute run, No. 160:

Revolutions per minute	274.4
Explosions per minute	131.6
Ratio explosions to double strokes	95.92
Mean effective pressure	76.53
Indicated horse-power	8.63
Brake horse-power	6.46
Mechanical efficiency	74.93
Corrected gas per indicated horse-power hour	19.577 cu. ft.
Corrected gas per brake horse-power	26.129 cu. ft.

That these results are not unusual, reference is also made to Fig. 7 and 8, Cards Nos. 4 and 6 of Run 140, previously given, in which the diagrams were repeated or traced 13 times without removing the indicator pencil, and giving 7.50 indicated horse-power, 5.73 brake horse-power, a mechanical efficiency of 76.39, and a corrected gas consumption of 20.44 cubic feet per indicated horse-power per hour, or 26.76 cubic feet per brake horse-power per hour.

In English text-books on the gas engine it is stated that the use of the hot tube as an igniting device is to be preferred to electric ignition chiefly on account of the skill required in keeping up the batteries and keeping the platinum points in working condition. That electric ignition has its individual peculiarities and troubles goes without saying; and, when the proportion of air to gas is not right, that late, but not early, ignition is just as possible with electric methods as with hot-tube methods. It is well, however, to understand just what the internal ailments are which are likely to affect the open hot-tube method of ignition, and hence this study of the subject. It should be said, however, that it does not follow that all hot-tube ignition methods and mechanisms are subject to all of the troubles here isolated and described; or that any one engine is likely to be afflicted with all of these troubles at any time in its life. There are a few external ailments, such as not having the hot tube hot enough, which was mentioned above in case No. 12; not having the proper supplies of gas and air to the Bunsen burner of the hot tube, the asbestos lining of the chimney not being of the right size, the hot tube itself burning out or becoming filled with soot or tarry matter, or being cracked by drafts of air if of porcelain, and the like, which it is not the purpose of this paper to discuss.

It is thought that a fuller knowledge of the possible external and internal organic troubles of the gas engine will remove it further from the realm of uncertainty to a position where it may be more fully depended upon for economical running and continuous service.

DISCUSSION.

Professor Emory.—I would like to ask the name of the generator described in the paper.

Professor Magruder.—The maker prefers that I should not state.

Professor Emory.—At the place where this engine is used, it

is greatly to be desired to have electric sparking, on account of the fact that the hot tubes are very liable to burn out, especially it would be one's luck to have them burn out when there is no attendant there. Several times this has happened in our plant, and some one has come in the nick of time to avert trouble. But the electric spark would be very much better in every respect. It seems to me that this special generator could be greatly improved by a very slight change in the cam arrangement, whereby the ignitions could be obtained at a sufficient point in the stroke to start the machine, and also to provide for ignition a little earlier as the machine comes to full speed. A number of the cards that are shown in the paper have been more or less duplicated by a number I have here from another machine, which show very materially the benefits of a slow explosion, that is, late burning rather than by an initial explosion followed by an attempt at adiabatic expansion. The test made was not sufficiently long to warrant the assertion as to the economy, but from a number of cards taken, the planimeters showed some wonderfully near approaches to the ideal card.

In most generators of the size mentioned in the paper, makers provide for both hot-tube and electric ignition. From the cards one sees that the ignition with hot tube is, as a rule, at instant of greatest compression and invariably at the beginning of the stroke. With the electric ignition this is very materially changed. In Card No. 1 (Fig. 340) of this discussion is shown the cycle of operations of a gas engine of 7½ horse-power nominal, recently tested by me, showing the early explosion of a charge with the hot tube. It is not a selected card, but the average of a number of similar ones at full load. Card No. 2 (Fig. 341), is from the same, with all conditions the same, except the hot tube was replaced by electric ignition by turning the torchlight out and switching in the current. With the electric-firing card it is noticeable that ignition is very tardy; in fact, it is a case of "stern chase."

This appears as a defect in the electric-ignition apparatus which the manufacturers have overlooked, or, at least, failed to remedy. Its cause arises from the fact that the electric ignition is produced by a spark from electrodes which are brought together by the recoil of a helical spring actuating a hammer, which is released from a cam connected to shaft operated from the crank shaft. The cam is ordinarily set to release the

spring just before the end of compression. The card above was taken with the cam set to do this when the wheel was run by hand at starting. When full speed is reached it is evident that the periodicity of the spring is too slow for the speed of piston, and the result is that with a position of cam which will start the engine there is too great a delay at full speed. Many attempts were made to start the motor with the cam set far enough back to give ignition spark at the beginning of the stroke, but the result was that a first explosion was obtained followed by one before the end of compression and reversing the motor and stopping the generator. Of course, with a starter of compressed air, the cam could be set so as to give an ignition at a desired point at full speed, but with small powers there is usually no starters considered necessary. In this case, however, its installation would be a great improvement. In many respects the electric ignition is to be desired.

Mr. Rudolph G. Schneble.—I have a few words to say on the hot tube, and that is that the hot tube depends on the amount of compression and on the reliability of the mixture which reaches the hot tubes. The hot tube must be so located that the mixture of gas and air which reaches it will be a good mixture every time—that is, one not contaminated with burnt gas and air, of which a certain amount always remains in the cylinder.

My experience with a hot tube has been mostly with an engine, where it was impossible to locate the hot tube to secure such a mixture to it. To lengthen, shorten, or to heat to a white heat would not help matters. The engine would not give over 75 per cent. of the power with a hot tube that it would develop with an electric igniting device.

I afterwards was consulted on the design of an engine, in which I suggested placing the hot tube directly over the top of the mixture valve (more often called the air valve), which would be over the chamber marked *B* in Mr. Magruder's paper, which entirely does away with the passage *D*. It gave a new and clean mixture to the hot tube each and every time. With such a mixture the tube need be heated but little over black hot, and I have known of tubes of common black iron pipe to last for six months, which is as long as composition tubes will last on some engines where the tube is not so well located.

Then again, as to the electric device spoken of by Mr. Emory. I have designed different devices for changing the time of ignition

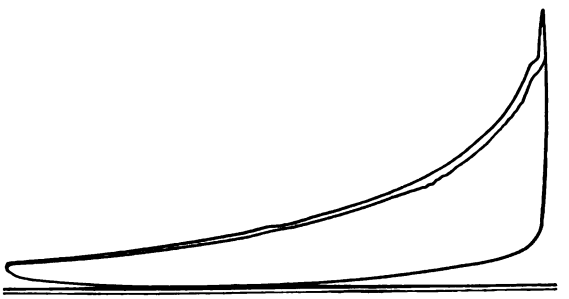
for starting and running the engine, just by simply turning an eccentric or flipper up or down to give an early or late ignition. as we call it—an early ignition for the regular running, a late ignition for starting the engine. The late ignition gives a card like No. 2, shown by Mr. Emory. An early ignition would give a card not nearly so round at the ignition point, and give possibly a much higher initial pressure than Mr. Emory's No. 1 card.

Mr. E. W. Roberts.—I should like to make a few remarks on the subject of electric ignition. I have seen a great many electrically ignited engines in which the ignition was not at the time at which it should be according to the design or according to the timing device. That is what has been the greatest stumbling block to the gas-engine designer, and is known as back firing or premature ignition. It is due to a great many causes, the principal one of which is projections in the cylinder, within the compression space, and one of the principal causes of this trouble is the location of the igniter points, so that they become highly heated and act in the same way as ignition tubes. That is a point which does not seem to have been grasped by a great many gas-engine designers, and I have seen many gas engines in which the electric current could be turned off and the gas engine keep on running. Premature ignition is also caused by using a poor quality of oil, from which carbon is deposited either in flakes or in small cones. These become very highly heated and also act as ignition devices. The misunderstanding of these matters has been the cause of a great deal of objection to electric ignition.

Professor Magruder.—I would like to ask Mr. Emory if he has noticed any difference in the mean effective pressure and the indicated horse-power, if the upper card was slightly rounded and the ignition was slightly later?

Professor Emory.—The tests of the engine have not yet been worked up, so I cannot speak positively about that. One thing was especially noticeable in those two cards: with the first card, with the hot tube, the speed was more fluctuating; there was apparently less gas used. With Card No. 2 (Fig. 341) the engine immediately began a labored effort, took more gas, and the explosions were not so violent. In every way there seemed to be a greater consumption of gas for less work done. In fact, the regular speed could not be obtained. The speed was not sufficient to work the governor. I think when giving Card

No. 2 (Fig. 341) no more than possibly 1 in 22 to 30 explosions were missed—about 22 to 30 explosions being required before reaching the desired speed. When giving Card No. 1 (Fig. 340) it would miss, on the load that we had, at least 1 in every 6 or 1 in 8. The late ignition gave a smoother performance, because the speed was more regular, and especially to be desired as it was used direct-connected by belt to a dynamo. It is not a very satisfactory type of electric connection. The engine mentioned has been put on the market to meet all conditions, but could be remedied in a very simple way, and so



No. 1. HOT TUBE

FIG. 340.

Magruder No. 2. ELECTRIC

FIG. 341.

make it an engine that can be started with less difficulty. The great difficulty in starting the engine is its chief fault. We hardly thought it was large enough to put in a pump and compressor to start. We thought we could start it by hand, and the manufacturers claim that we can, which is all true and all very well, if we are satisfied with so late an explosion as almost one-fifth or a quarter.

Mr. Roberts.—I think I can answer Professor Magruder's question. I recently had a talk with Mr. Burger, of the Woolley Manufacturing Company, at Anderson, Indiana, in which he claimed that he could do that; that from a round-top card he got a larger area than from one in which it was pointed.

Mr. Willis.—Can I ask the two gentlemen who have preceded, if they can give me information about the time of explosion in those engines, like the Hornsby-Akroyd, which have neither hot-tube nor electric ignition? Is that regulated by the distance through which the hot gases have to pass? Possibly Mr. Emory might answer the question.

Professor Emory.—I could not give any information on that which would be of any value at all.

Professor Magruder.—What I particularly referred to in my question you can see in Fig. 307, page 981. We have there two diagrams, one showing a sharp, instantaneous ignition and the other with a rounded top. I was desirous of knowing if others had had the same experience. Answering Mr. Willis, I would say that the Hornsby-Akroyd is an oil engine. The oil is injected into a large pot placed outside of the cylinder, and where it is gasified and ignited; and is quite different from a gas engine using a fuel already gasified.

Mr. Willis.—Those engines work with gas just as they do with the oil. They will make them to work on gas without the oil.

Mr. James A. Charter.—The paper treats very intelligently on the internal action of the engine, as well as the various causes which would have to do with the time of ignition when the hot tube is used. A timing valve in connection with a hot tube would, to a certain degree, make the point of ignition more positive, but the valves themselves are subject to wear, corrosion, and warping from heat, and have been found to be very unsatisfactory in practice, so much so that the Fairbanks-Morse engine has been fitted with a mechanically operated electric igniter.

The igniter is operated from an incline cam on the large gear, and by suitable mechanical connections motion is conveyed to a spring catch which is attached to an oscillating electrode. The construction of the igniter is simple, and therefore not likely to get out of order, and as it is strongly built it is not soon affected by wear. Platinum points are provided on the movable as well as the insulated electrode, therefore corrosion does not quickly affect the sparking points, and these igniters have been used on our engines, kept in constant service for a period of ninety days and nights without attention or adjusting.

It will be clearly seen that as the igniter is mechanically oper-

ated, the time of separating the points is the same at all times under all conditions; therefore, the charge in the cylinder is always ignited at a pre-determined time. The variation in the charge or the heat of the engine would only slightly effect the perpendicular explosion line. The point of ignition always remaining the same with an over-charged mixture (one having too much gas, for instance), the line would divert from a straight perpendicular on account of the slow burning of the charge, but the indicator card would clearly show the point of ignition having been kept practically constant, the same as when the mixture was an ideal one. The same might be said of the heat of the cylinder caused by the changing of the flow of water through the jackets.

The above described igniter receives its current from a primary battery of either the Edison-La Lande type, or a bank of standard carbon batteries used in connection with the spark coil for intensifying the spark. The above batteries are good for an ordinary run of six to twelve months without recharging, and the satisfaction which this igniter is giving to both the purchaser and the manufacturer is universal.

*Professor Magruder.**—Replying to Professor Emory, I would state that on most gas engines using electric ignition there is a starting cam whereby the ignition is made purposely late until the requisite momentum has been obtained, and then the cam is advanced so as to give an earlier and more effective ignition, so that compressed air for starting is not necessary—this is well shown in Fig. 304. If hot tubes are made of nickel-steel, the chances of their burning out are reduced to a minimum.

The troubles due to electric ignition do not form part of the subject matter of this paper, and further discussion of them should be postponed.

---

* Author's closure, under the Rules.

No. 862.*

CYLINDER PROPORTIONS FOR COMPOUND AND TRIPLE-EXPANSION ENGINES.

BY BERT C. BALL, NEW YORK CITY.

(Junior Member of the Society.)

THE amount of literature on this subject would fill many volumes, and yet the solution of the question is not by any means settled at the present time, our best and most prominent engineers holding very different opinions. There are two extremes, with very ardent supporters at each end, and the middle ground is well filled with those who are in doubt and think that a happy medium is the safest position. They can easily shift to whichever side seems to be in the ascendent.

The question on which harmony of opinion is shattered is, "Shall we have terminal drop in any cylinder but the last, in multiple-expansion engines?" I think the weight of authority, especially among the older engineers, is on the side of "no drop." Among the most prominent engineers on this side are Messrs. Sulzer, Leavitt, Reynolds, F. W. Dean, and Professors Thurston and Denton. The other school, who although less numerous are probably more emphatic in their expressions, hold that there should be terminal drop. Unfortunately, we have no series of experiments to which we can point, and say without fear of contradiction, "This proves conclusively that there should be, or that there should not be, drop."

Many tests have been made which point one way or the other, but there are always circumstances connected with these tests which either side can point out as unfair to their side of the question; and when we realize the many conditions which can materially alter the results of a trial, it is not hard to see the difficulty

* Presented at the seventh Junior meeting, March 6, 1900, in New York, at the house of the American Society of Mechanical Engineers, and made a part of the Proceedings of the Cincinnati meeting, by direction of the Publication Committee, for record in Volume XXI. of the *Transactions*.

of proving a theory to the satisfaction of the other side. Results, however, are what we are after, and at the present time the best results seem to have been obtained in engines having large ratio of cylinders and a moderate amount of drop.

Before discussing this question, I wish to take up the drawing of indicator diagrams for multiple-expansion engines, for all our theories and calculations are based on these diagrams. There are numerous methods of drawing diagrams, which are more or less accurate and convenient. Practically all of them disregard the effect of compression, and in many cases, especially in engines of moderately large clearance, this becomes very important.

If compression always fills the clearance space to initial pressure, this would become negligible, but inasmuch as compression *should not* fill the clearance space to obtain the best economy, and as it seldom does, we should take this part of the diagram into account.

Several years ago I devised a system for constructing diagrams which has some points of advantage over any other with which I am familiar.

Fig. 342 illustrates this method, and it can be explained best by following through the construction for a particular case.

In any case to be worked out there are certain points which must be given or assumed in order to make a solution possible. For instance, boiler pressure and back pressure (absolute) must be known. In the case of a condensing engine, we will assume the amount of vacuum in the cylinder and the initial pressure, B and C, are thus determined. Then we have to decide on some questions, such as ratio of expansion, cut-off in high and low pressure cylinders, etc.

After deciding upon the ratio of expansion, point D can be located. The clearance in both cylinders must of course be known, and then we can construct an expansion curve from D. It now becomes necessary to decide upon either the cut-off in the low-pressure cylinder or the received pressure. In either case, point E will be determined.

The line EK will ordinarily be nearly horizontal, because compound engines usually have large enough receivers to maintain a practically constant pressure in the receiver. Some styles of engines, however, have small receivers, and then it becomes necessary to locate point K accurately. In this case the line EK can be constructed as an expansion curve, starting from E,

using for clearance volume, $R + C_1 + C_2 + \frac{V}{r\,1\,-}$, in which R is the received volume, C_1 clearance in low-pressure cylinder, C_2 clearance in high-pressure cylinder, V volume of low-pressure cylinder, and r cylinder ratio. This gives a clearance volume referred to the low-pressure cylinder, from which an expansion curve can be constructed from E to K.

Then it is necessary to locate point F, either by deciding upon the point of cut-off in this cylinder or upon the amount of drop

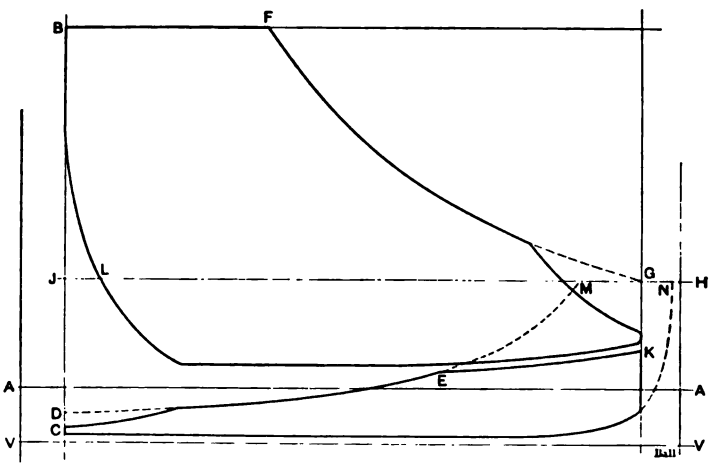


FIG. 342.

at release. The expansion curve from F' should be carried to G, and the line HJ drawn through G.

The style of valve gear being known, we can now determine the points of release and compression, and construct compression curves. The low-pressure expansion and compression curves should now be carried to the line HJ. The diagrams are now complete, and it only remains to determine the size and ratio of cylinders.

To determine the cylinder ratio, it is only necessary to measure the lines LG and MN. The ratio of these two lines is the cylinder ratio. This of course assumes that all of the steam which is exhausted from the high-pressure cylinder appears at cut-off in the low-pressure cylinder. In the many economical engines with jackets and superheaters this will be found to be the case, but in every engine there is a certain percentage of the steam

exhausted from the high-pressure cylinder which appears in the low-pressure cylinder.

In good, high-speed, single-valve engines, without jackets or superheaters, I have found that about 90 per cent. is a safe figure. To allow for this it is necessary to use 90 per cent. of the length of the line LG, as compared with the line MN, to determine the cylinder ratio. These diagrams are drawn with hyperbolic expansion curves, which are accurate enough ordinarily. The same system, however, could be used with saturation curves.

It can be seen, of course, that it is not necessary to start the construction from any one point, for the system is equally convenient for starting at any other point if enough data are given to make a construction possible.

The principal feature of this method is the bringing of all expansion and compression curves to a common line, and measuring the amount of steam on that line to determine the cylinder ratio.

After completing the diagram we can slant the admission line, round corners, and make such other alterations as the nature of the engine under consideration requires.

In order to decide intelligently what cylinders should be used for a given case, it is necessary to take into consideration a great many factors.

In the first place, if an engine is to be designed for highest economy it will not have, ordinarily, a great overload capacity. Right here is where a great many engineers make mistakes. In writing specifications for engines, they will insert conditions which make it practically impossible for the engine, under its running conditions, to give its best economy. For instance, we often see cases where an engine which will usually run with a vacuum must be guaranteed to carry 25 per cent. overload without vacuum and 40 per cent. with vacuum. If an engine is designed to operate economically with a vacuum, it is practically certain that without vacuum it would hardly develop its rated capacity, to say nothing of overload.

Engineers who are seeking economical performance must not expect great overload capacity. In non-condensing engines designed for 100 pounds or less, the overload capacity for an economical engine becomes *very* small. If the engine is to be operated as a condensing engine, but on account of some peculiar conditions there is a probability of running the engine without a

vacuum part of the time, the cylinder proportions must either be modified from those for best economy, or some provisions made for a by-pass to the low-pressure cylinder.

Leaving other conditions out for the present and seeking economy primarily, we come to the great problem with which steam engineers have struggled since the advent of the steam engine. There is a vast field for mathematicians in the thermodynamics of the steam engine, but when we have followed them through their wanderings, and been introduced to the cycles of Carnot, Rankin, *et al.*, we can sum it all up by stating that, eliminating cylinder condensation, the best economy can be obtained by an engine working steam between two pressures when the steam is admitted at the higher pressure, expanded to the lower pressure and discharged, and the clearance space filled by compression to the higher pressure.

The elimination of condensation simplifies the problem immensely, at least theoretically. If we *could* eliminate condensation, the highest possible economy we could obtain theoretically would be realized in a single-cylinder engine, in which the expansion was carried to the pressure of discharge, and compression filled the clearance spaces to initial pressure.

The tests conducted by Chief Engineer Isherwood, United States Navy, and others, have settled positively that using steam in this manner does not give the highest economy, on account of condensation.

The reason why condensation effects this change *is not* that *some* steam is condensed in the cylinder each stroke, but that the condensation is *not* in *proportion* to the steam admitted and the work done, but nearly a fixed amount per stroke for a given set of conditions. If more steam is admitted, the amount condensed is practically the same, but the proportion which is condensed becomes less; and for this reason it is economical to throw away some work by free expansion at each end of the stroke, for, in so doing, the total amount of work done per stroke is increased, and the condensation, which is a total loss, becomes a smaller proportion of the steam used.

Referring to Fig. 343, we can see this more clearly.

This diagram, *ODCB*, would be a very fine one for an engine using highly superheated steam, or some gas which is not subject to the difficulties due to condensation; but we know that this is not economical for ordinary steam engines, and the reason

why it is not is, as I said, that the condensation is a fixed amount each stroke, and if we have a small amount of work done, the percentage of condensation is large. If we increase the area of work a little, as indicated by the light line *SR*, we have then thrown away the amount of work represented by *RAD*; but we have added *SRDO*, which is, of course, very large in proportion to the amount thrown away.

Condensation, which is practically the same in both cases, becomes a much smaller proportion of the steam used, and the economy of the whole is improved. The truth of this has been

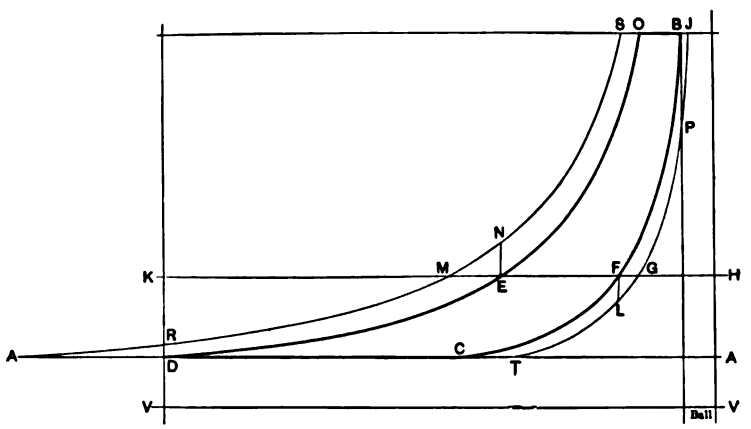


FIG. 343.

proven by so many accurate tests that there is no doubt about it. The question now is, "Why should we have drop at release in one cylinder and not have it in another cylinder?"

Suppose we divide this diagram into two diagrams by the line *HK*, and consider that the diagram above this line is produced by one engine and that below by another engine. If the atmospheric pressure had happened to be at *HK* instead of *AA*, we could then consider the diagram *OEFB* as from a single-cylinder non-condensing engine.

On Mars it may be that the atmospheric pressure is at *HK*. If it is, then their non-condensing engines would produce cards about like *OEFB*. From what we know of steam and the laws of condensation, it does not seem possible that this card would give maximum economy for the single-cylinder engine, and it is practically certain that *SNEGPB* would give better economy. In this

case the losses by free expansion at N and P are more than made up by the reduction in the proportion of cylinder condensation.

If, therefore, drop is necessary for maximum economy at one part of the expansion curve, why should it not be advantageous at any other point? Of course the amount will vary at different points, but it seems logical that if it is desirable at one pressure it is also desirable at other pressures. There is another condition regarding drop in the high-pressure cylinder which does not exist in the low, and that is the improved condition of the steam, due to the free expansion.

At release in the low-pressure cylinder the improvement in the quality of steam by free expansion does no good, while in the high-pressure, any improvement in steam at release improves the action of the low-pressure cylinder. It seems, therefore, that there should always be more drop in the high-pressure cylinder than the low.

Some brilliant mind conceived the idea that by dividing the range of temperature between two or more cylinders condensation would be reduced. From that time to the present day the great object of most engineers seems to have been to produce what is considered by them a perfect diagram, in which expansion is carried through successive cylinders without loss by free expansion.

When it was found advantageous to divide the range of temperature into two or more stages, each successive cylinder should have been treated as an engine working between the two pressures assigned to it, and studied to get the greatest economy out of each cylinder.

It is unfortunate that some one who has time and money to spend has not, in the interest of science, built an engine which could be used as a test engine, to determine some facts upon which we could stand as firmly as we stand on the results of the tests of Chief Engineer Isherwood, regarding cylinder condensation.

This test engine should be fitted with about three interchangeable cylinders, which could be used one at a time. One cylinder should be designed to use steam from a few pounds above atmosphere to about 28 inches vacuum. The next one to use steam from about 150 pounds pressure to a few pounds below atmosphere, and the third should be capable of using steam from about 250 pounds pressure to about 60 pounds pressure.

Then, if you wanted to design a triple-expansion engine to work

steam between 200 pounds pressure and 28 inches vacuum, you could divide the range of temperature into three stages and run a series of three tests on this engine for each cylinder, using steam in each case between the temperatures and pressures corresponding to the three stages. From these tests a curve could be plotted for each stage, and the indicator diagram of maximum economy for that stage determined. These cards could then be combined, and a triple designed to reproduce this combined diagram.

This method would not, of course, take into account every condition existing in the triple. For instance, the improvement in the quality of steam due to free expansion at release. On account of this condition, the engine to give the maximum economy should have greater terminal drop than these tests would indicate.

The reasoning which requires terminal drop in the single-cylinder engine certainly applies to compound, and recent tests are tending to prove this beyond doubt.

Our friends across the Atlantic are, almost without exception, opposed to this theory. They have obtained wonderful results from engines without drop, and their opinion should be respected; but simply because some Sulzer triples have made world records, it does not prove the point in question, and there is no record of the Sulzer compounds having equalled the economy of some of our large ratio compounds on this side of the water.

As far as I know, there has been no triple-expansion engine of economical type built to produce indicator cards showing terminal drop in the high and intermediate cylinders, and it is not at all improbable that, as the development of economical engines continues, triples will be made along this line which will excel even the Sulzer engines.

The first compound engines with large cylinder ratios, of which I have been able to learn, were made by Mr. S. B. Greacen, of Perth Amboy, N. J. I think he is without doubt the pioneer in this field, and I am glad to have the opportunity to put his work on record. I desire to quote part of a letter which he wrote to me, in answer to an inquiry of mine on this subject:

"Replying to yours of yesterday, would say to you that I built my first compound engine in the winter of 1872–73. I built it for a pleasure launch, for my own use. The engine that I built at that time had cylinders 4 and 8 inches diameter by 8-inch stroke. Both cylinders were steam jacketed and were operated by one flat valve, and the high pressure had an independent adjust-

able cut-off. My boiler was 26 inches diameter (vertical) and 5 feet high, and would carry 250 pounds steam.

"In running the engine myself, I found out many things which surprised me. The first thing I noticed was that the cut-off was of no benefit as regards economy (rather a detriment); theoretically it was all right, practically no use. I discarded the cut-off, and bushed the high-pressure cylinder so that the ratio was 6 to 1, and found decided improvement.

"Thinking if I went still farther I might further improve the engine by increasing the ratio to 10 to 1, I put another bushing in the high-pressure cylinder and raised the boiler pressure higher, and found that I had lost, instead of gaining, by the change from 6 to 1. There were many things that surprised and puzzled me.

"My flat valve was trying my engine by reason of the friction, and the piston-rod packing burned out and created so much friction that it did not pay. My next move was to bush the cylinder 7 to 1. It seemed to be a slight improvement on 6 to 1, but the valve friction was a serious matter, so after laying my boat up for the winter I made a new pair of cylinders with piston valves and a ratio of 7 to 1, and tried it in the spring of 1874. It was a great improvement on the old cylinders, and is about the same thing I am building to-day, after trying many other styles of cylinders.

"I am now building for my own use a steam yacht 96 feet long, 17 foot beam, with engine No. 65, which has cylinders 9 and 25 diameter by 12 stroke, piston valves, and about the same thing as the one I built in 1874.

"The original engine which I built in 1872–3 was sold to General Gilmore, of the United States Army, in 1878, and is still in use in the boat, as I built it, somewhere in the South, near Jacksonville, Fla.

"One result of my experiments in 1873 was to decide, in my mind, a rule for the proper ratio of cylinders in proportion to the steam pressure used, which I will give you:

60	pounds	of	steam,	cylinder	ratio	4	to	1.
85	"	"	"	"	"	5	"	1.
110	"	"	"	"	"	6	"	1.
135	"	"	"	"	"	7	"	1.
160	"	"	"	"	"	8	"	1.

"After many years' practice, I do not see any reason to change my ideas from what I learned in 1873.

"One very successful engine which I built in 1884 had cylinders 16 and 35 by 24 stroke, and was allowed to carry 80 pounds only. It was built for R. G. Packard, 130 Pearl Street, New York City, and he still owns it."

In 1891 Mr. George I. Rockwood made some tests of a triple-expansion engine which was so arranged that the intermediate cylinder could be cut out. This engine was tested as a triple and as a compound, and reported to the Society in Volume XIII. of the *Transactions.*

I will not discuss the comparisons of the two tests, for I do not think the triple had a fair show, but the record of the compound with a ratio of 5.7 to 1 was sufficiently remarkable to attract the attention of engineers. At that time Mr. Rockwood advanced the theory that a triple-expansion engine possessed no advantage over a compound on the score of economy. He has since maintained the same position in a paper read before the Providence Association of Mechanical Engineers, in December, 1898.

I do not agree with him on this point, and think that he has drawn wrong conclusions from his tests. His strong fight has been on the question of terminal drop, and in that I agree with him heartily. The comparisons he has drawn are always with triples in which there is no drop.

Mr. Rockwood seemed to have reasoned that, because a compound engine with large cylinder ratio and drop has practically equalled the records of triple-expansion engines without drop, therefore there is no advantage in the triple. If drop is advantageous, why should it not be equally efficient in the triple? In fact, the higher the pressure from which a given amount of drop occurs, the less the loss by free expansion.

This question of terminal drop was discussed, and the theory elaborated, by my father, Mr. F. H. Ball, in a paper presented to the Society in 1894, and will be found in Volume XV. of the *Transactions.*

The great obstacle in the path of economical engines, which we are all trying to reduce to as low a limit as possible, is cylinder condensation. To accomplish this object, there are three important means which we can employ.

First, reduction of area, subject to steam under varying pressure and temperature.

Second, reduction of range of temperature.

able cut-off. My boiler was 26 inches diameter
5 feet high, and would carry 250 pounds steam
"In running the engine myself, I found
surprised me. The first thing I noticed
of no benefit as regards economy (rat
cally it was all right, practically
off, and bushed the high-pressure
to 1, and found decided impro
"Thinking if I went still
engine by increasing the
in the high-pressure c
and found that I h
6 to 1. There w
"My flat v
and the p
friction
cylind
but
ich is too
n, cylinder
ainst, but any
cylinders. In-
a-pressure cylinder
r of expansions the
would seem to be not so
ald be done at all as how
y looking at Fig. 343 we can see
drop, the amount of work lost is very
ne reduction of area for condensation is
considerable, the cylinder areas being represented approxi-
mately by the lines MG and EG respectively. If this is true for
compounds, it certainly is true for triples.
The saving due to reduction of range of temperature has been
proven beyond doubt, and the only question seems to be, "What
is the best method of dividing the range between two or more
cylinders?" Some say "Equal ranges," and some say "Unequal
ranges." The question of superheat comes in, to further increase
the difficulty of deciding upon the proper ranges of temperature.

The saving due to steam jackets and superheaters seems to be more on account of increased reëvaporation rather than to reduction of initial condensation. It is probable that the initial condensation is somewhat reduced, but the reëvaporation is certainly increased.

In some tests of compound engines of Mr. Rockwood's design, at the Grosvenordale Mills, several records of less than 13 pounds of water per indicated horse-power per hour were made, one test showing less than 12 pounds. The steam pressure was 150 pounds, and the vacuum 26½ inches.

About the same economy was obtained from a Leavitt pumping engine at Louisville, Ky. This engine had 150 pounds of steam and 27½ inches vacuum in the low-pressure cylinder. The ratio of cylinder was 4 to 1. The stroke of this engine was 10 feet, and the piston speed 370 feet.

From these comparisons it seems probable that a compound having large cylinder ratio and drop, under as favorable conditions as the Leavitt engine, will appreciably reduce the water rate of that engine, which is considerably in the lead of all other

compound engines in which expansion is carried to the line of back pressure in high-pressure cylinders.

It seems, therefore, fairly well settled that Mr. Rockwood, by od engineering, has produced record-breaking compounds. He not only succeeded in obtaining a record of less than 12 ds of water per horse-power per hour, in one engine, but btained considerably less than 13 pounds in a number of , and these records seem to place his engines in a class by es.

ection with large cylinder ratios, I would like to call

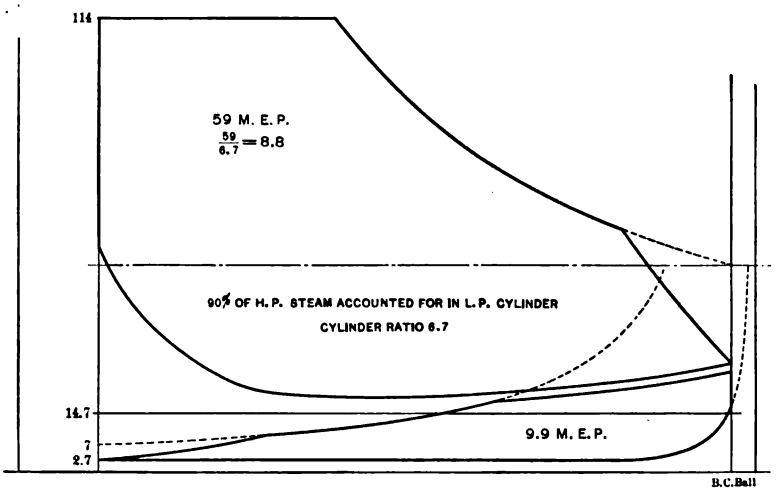


FIG. 344.

your attention to some cards which were loaned to me by the American Engine Company. These are cards from which two engines were designed. These engines are of the style recently built by that company, in which one valve controls the steam for both cylinders.

The first card, Fig. 344, is for 110 pounds boiler pressure, and is being built to run their shop. When it is completed, which will be very soon, a series of tests will be conducted, and it is quite possible that they may throw some light on the subject of cylinder proportions.

In these diagrams, I desire to call your attention to the difference it would make by leaving out of consideration the compression curve.

using for clearance volume, $R + C_1 + C_2 + \frac{V}{r\,1\,-}$, in which R is the received volume, C_1 clearance in low-pressure cylinder, C_2 clearance in high-pressure cylinder, V volume of low-pressure cylinder, and r cylinder ratio. This gives a clearance volume referred to the low-pressure cylinder, from which an expansion curve can be constructed from E to K.

Then it is necessary to locate point F, either by deciding upon the point of cut-off in this cylinder or upon the amount of drop

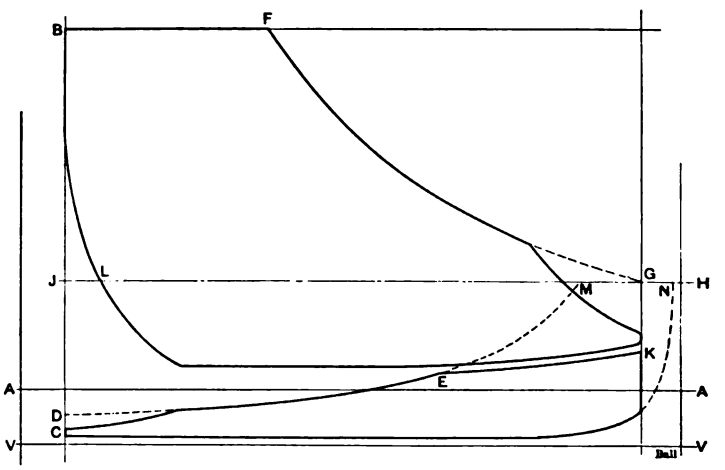


FIG. 342.

at release. The expansion curve from F should be carried to G, and the line IIJ drawn through G.

The style of valve gear being known, we can now determine the points of release and compression, and construct compression curves. The low-pressure expansion and compression curves should now be carried to the line IIJ. The diagrams are now complete, and it only remains to determine the size and ratio of cylinders.

To determine the cylinder ratio, it is only necessary to measure the lines LG and MN. The ratio of these two lines is the cylinder ratio. This of course assumes that all of the steam which is exhausted from the high-pressure cylinder appears at cut-off in the low-pressure cylinder. In the many economical engines with jackets and superheaters this will be found to be the case, but in every engine there is a certain percentage of the steam

exhausted from the high-pressure cylinder which appears in the low-pressure cylinder.

In good, high-speed, single-valve engines, without jackets or superheaters, I have found that about 90 per cent. is a safe figure. To allow for this it is necessary to use 90 per cent. of the length of the line LG, as compared with the line MN, to determine the cylinder ratio. These diagrams are drawn with hyperbolic expansion curves, which are accurate enough ordinarily. The same system, however, could be used with saturation curves.

It can be seen, of course, that it is not necessary to start the construction from any one point, for the system is equally convenient for starting at any other point if enough data are given to make a construction possible.

The principal feature of this method is the bringing of all expansion and compression curves to a common line, and measuring the amount of steam on that line to determine the cylinder ratio.

After completing the diagram we can slant the admission line, round corners, and make such other alterations as the nature of the engine under consideration requires.

In order to decide intelligently what cylinders should be used for a given case, it is necessary to take into consideration a great many factors.

In the first place, if an engine is to be designed for highest economy it will not have, ordinarily, a great overload capacity. Right here is where a great many engineers make mistakes. In writing specifications for engines, they will insert conditions which make it practically impossible for the engine, under its running conditions, to give its best economy. For instance, we often see cases where an engine which will usually run with a vacuum must be guaranteed to carry 25 per cent. overload without vacuum and 40 per cent. with vacuum. If an engine is designed to operate economically with a vacuum, it is practically certain that without vacuum it would hardly develop its rated capacity, to say nothing of overload.

Engineers who are seeking economical performance must not expect great overload capacity. In non-condensing engines designed for 100 pounds or less, the overload capacity for an economical engine becomes *very* small. If the engine is to be operated as a condensing engine, but on account of some peculiar conditions there is a probability of running the engine without a

Figs. 347 and 348 show diagrams from which I have proportioned triple-expansion cylinders for an engine working under the conditions of this quadruple, which I believe would be more economical than that engine.

In the first place, the expansion is carried to a much lower terminal pressure, giving forty-three expansions, as compared with about twenty-four in the quadruple. The temperature ranges are also more nearly uniform in the different cylinders.

It will be noticed that the terminal drop is only about 3½ pounds in the low-pressure cylinder, and increases to 7 pounds

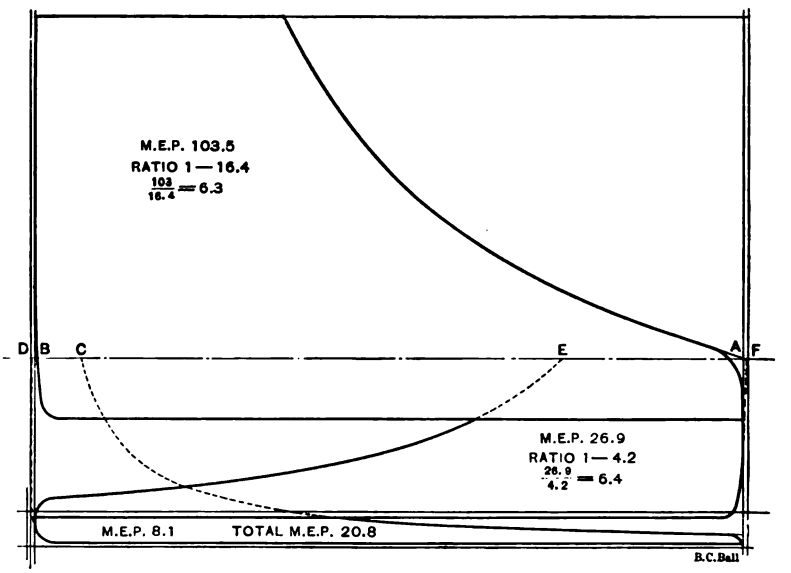


FIG. 347.

in the intermediate-pressure cylinder, and 24 pounds in the high-pessure cylinder. To develop the same power as in the quadruple, the cylinders for the triple would be 19 inches, 37½ inches, and 76½ inches, the cylinder ratios being, high pressure to intermediate pressure, 1 to 3.9; high pressure to low pressure, 1 to 16.4.

Dividing the low-pressure cylinder into two, and placing the high and intermediate cylinders, each tandem, in a low-pressure cylinder would give the same arrangement of cylinders as in the quadruple, and in this case the cylinders would be 19 inches, 37½ inches, and two 54 inches. The steam per indicated horse-power per hour at release in the high-pressure cylinder would be

why it is not is, as I said, that the condensation is a fixed amount each stroke, and if we have a small amount of work done, the percentage of condensation is large. If we increase the area of work a little, as indicated by the light line *SR*, we have then thrown away the amount of work represented by *RAD*; but we have added *SRDO*, which is, of course, very large in proportion to the amount thrown away.

Condensation, which is practically the same in both cases, becomes a much smaller proportion of the steam used, and the economy of the whole is improved. The truth of this has been

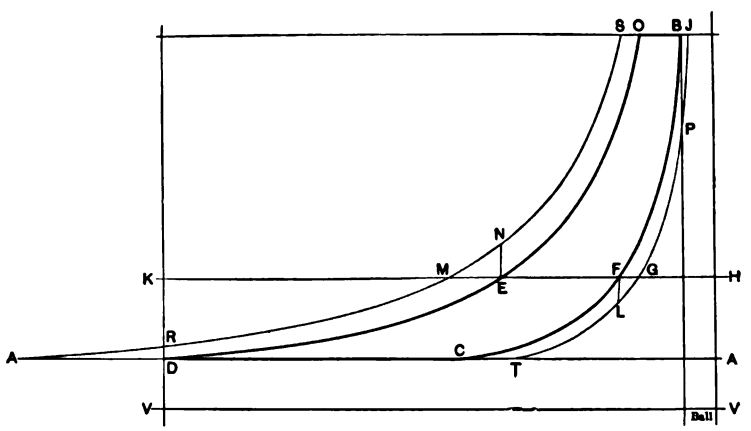


FIG. 343.

proven by so many accurate tests that there is no doubt about it. The question now is, "Why should we have drop at release in one cylinder and not have it in another cylinder?"

Suppose we divide this diagram into two diagrams by the line *HK*, and consider that the diagram above this line is produced by one engine and that below by another engine. If the atmospheric pressure had happened to be at *HK* instead of *AA*, we could then consider the diagram *OEFB* as from a single-cylinder non-condensing engine.

On Mars it may be that the atmospheric pressure is at *HK*. If it is, then their non-condensing engines would produce cards about like *OEFB*. From what we know of steam and the laws of condensation, it does not seem possible that this card would give maximum economy for the single-cylinder engine, and it is practically certain that *SNEGPB* would give better economy. In this

case the losses by free expansion at N and P are more than made up by the reduction in the proportion of cylinder condensation.

If, therefore, drop is necessary for maximum economy at one part of the expansion curve, why should it not be advantageous at any other point? Of course the amount will vary at different points, but it seems logical that if it is desirable at one pressure it is also desirable at other pressures. There is another condition regarding drop in the high-pressure cylinder which does not exist in the low, and that is the improved condition of the steam, due to the free expansion.

At release in the low-pressure cylinder the improvement in the quality of steam by free expansion does no good, while in the high-pressure, any improvement in steam at release improves the action of the low-pressure cylinder. It seems, therefore, that there should always be more drop in the high-pressure cylinder than the low.

Some brilliant mind conceived the idea that by dividing the range of temperature between two or more cylinders condensation would be reduced. From that time to the present day the great object of most engineers seems to have been to produce what is considered by them a perfect diagram, in which expansion is carried through successive cylinders without loss by free expansion.

When it was found advantageous to divide the range of temperature into two or more stages, each successive cylinder should have been treated as an engine working between the two pressures assigned to it, and studied to get the greatest economy out of each cylinder.

It is unfortunate that some one who has time and money to spend has not, in the interest of science, built an engine which could be used as a test engine, to determine some facts upon which we could stand as firmly as we stand on the results of the tests of Chief Engineer Isherwood, regarding cylinder condensation.

This test engine should be fitted with about three interchangeable cylinders, which could be used one at a time. One cylinder should be designed to use steam from a few pounds above atmosphere to about 28 inches vacuum. The next one to use steam from about 150 pounds pressure to a few pounds below atmosphere, and the third should be capable of using steam from about 250 pounds pressure to about 60 pounds pressure.

Then, if you wanted to design a triple-expansion engine to work

steam between 200 pounds pressure and 28 inches vacuum, you could divide the range of temperature into three stages and run a series of three tests on this engine for each cylinder, using steam in each case between the temperatures and pressures corresponding to the three stages. From these tests a curve could be plotted for each stage, and the indicator diagram of maximum economy for that stage determined. These cards could then be combined, and a triple designed to reproduce this combined diagram.

This method would not, of course, take into account every condition existing in the triple. For instance, the improvement in the quality of steam due to free expansion at release. On account of this condition, the engine to give the maximum economy should have greater terminal drop than these tests would indicate.

The reasoning which requires terminal drop in the single-cylinder engine certainly applies to compound, and recent tests are tending to prove this beyond doubt.

Our friends across the Atlantic are, almost without exception, opposed to this theory. They have obtained wonderful results from engines without drop, and their opinion should be respected; but simply because some Sulzer triples have made world records, it does not prove the point in question, and there is no record of the Sulzer compounds having equalled the economy of some of our large ratio compounds on this side of the water.

As far as I know, there has been no triple-expansion engine of economical type built to produce indicator cards showing terminal drop in the high and intermediate cylinders, and it is not at all improbable that, as the development of economical engines continues, triples will be made along this line which will excel even the Sulzer engines.

The first compound engines with large cylinder ratios, of which I have been able to learn, were made by Mr. S. B. Greacen, of Perth Amboy, N. J. I think he is without doubt the pioneer in this field, and I am glad to have the opportunity to put his work on record. I desire to quote part of a letter which he wrote to me, in answer to an inquiry of mine on this subject:

"Replying to yours of yesterday, would say to you that I built my first compound engine in the winter of 1872–73. I built it for a pleasure launch, for my own use. The engine that I built at that time had cylinders 4 and 8 inches diameter by 8-inch stroke. Both cylinders were steam jacketed and were operated by one flat valve, and the high pressure had an independent adjust-

able cut-off. My boiler was 26 inches diameter (vertical) and 5 feet high, and would carry 250 pounds steam.

"In running the engine myself, I found out many things which surprised me. The first thing I noticed was that the cut-off was of no benefit as regards economy (rather a detriment); theoretically it was all right, practically no use. I discarded the cut-off, and bushed the high-pressure cylinder so that the ratio was 6 to 1, and found decided improvement.

"Thinking if I went still farther I might further improve the engine by increasing the ratio to 10 to 1, I put another bushing in the high-pressure cylinder and raised the boiler pressure higher, and found that I had lost, instead of gaining, by the change from 6 to 1. There were many things that surprised and puzzled me.

"My flat valve was trying my engine by reason of the friction, and the piston-rod packing burned out and created so much friction that it did not pay. My next move was to bush the cylinder 7 to 1. It seemed to be a slight improvement on 6 to 1, but the valve friction was a serious matter, so after laying my boat up for the winter I made a new pair of cylinders with piston valves and a ratio of 7 to 1, and tried it in the spring of 1874. It was a great improvement on the old cylinders, and is about the same thing I am building to-day, after trying many other styles of cylinders.

"I am now building for my own use a steam yacht 96 feet long, 17 foot beam, with engine No. 65, which has cylinders 9 and 25 diameter by 12 stroke, piston valves, and about the same thing as the one I built in 1874.

"The original engine which I built in 1872–3 was sold to General Gilmore, of the United States Army, in 1878, and is still in use in the boat, as I built it, somewhere in the South, near Jacksonville, Fla.

"One result of my experiments in 1873 was to decide, in my mind, a rule for the proper ratio of cylinders in proportion to the steam pressure used, which I will give you:

60	pounds	of	steam,	cylinder	ratio	4	to	1.
85	"	"	"	"	"	5	"	1.
110	"	"	"	"	"	6	"	1.
135	"	"	"	"	"	7	"	1.
160	"	"	"	"	"	8	"	1.

"After many years' practice, I do not see any reason to change my ideas from what I learned in 1873.

"One very successful engine which I built in 1884 had cylinders 16 and 35 by 24 stroke, and was allowed to carry 80 pounds only. It was built for R. G. Packard, 130 Pearl Street, New York City, and he still owns it."

In 1891 Mr. George I. Rockwood made some tests of a triple-expansion engine which was so arranged that the intermediate cylinder could be cut out. This engine was tested as a triple and as a compound, and reported to the Society in Volume XIII. of the *Transactions*.

I will not discuss the comparisons of the two tests, for I do not think the triple had a fair show, but the record of the compound with a ratio of 5.7 to 1 was sufficiently remarkable to attract the attention of engineers. At that time Mr. Rockwood advanced the theory that a triple-expansion engine possessed no advantage over a compound on the score of economy. He has since maintained the same position in a paper read before the Providence Association of Mechanical Engineers, in December, 1898.

I do not agree with him on this point, and think that he has drawn wrong conclusions from his tests. His strong fight has been on the question of terminal drop, and in that I agree with him heartily. The comparisons he has drawn are always with triples in which there is no drop.

Mr. Rockwood seemed to have reasoned that, because a compound engine with large cylinder ratio and drop has practically equalled the records of triple-expansion engines without drop, therefore there is no advantage in the triple. If drop is advantageous, why should it not be equally efficient in the triple? In fact, the higher the pressure from which a given amount of drop occurs, the less the loss by free expansion.

This question of terminal drop was discussed, and the theory elaborated, by my father, Mr. F. H. Ball, in a paper presented to the Society in 1894, and will be found in Volume XV. of the *Transactions*.

The great obstacle in the path of economical engines, which we are all trying to reduce to as low a limit as possible, is cylinder condensation. To accomplish this object, there are three important means which we can employ.

First, reduction of area, subject to steam under varying pressure and temperature.

Second, reduction of range of temperature.

Third, steam jackets and superheaters.

The first is the most important, and it is the one which is too often overlooked. It is not only surfaces on piston, cylinder head, and cylinder walls which we must guard against, but any surfaces subject to the varying pressure in the cylinders. Increasing the cylinder ratio by reducing the high-pressure cylinder reduces this surface, leaving the total number of expansions the same.

Looking at this question logically, it would seem to be not so much a question of whether this should be done at all as how much of it should be done; for by looking at Fig. 343 we can see that, by a small amount of drop, the amount of work lost is very small (NME), and the reduction of area for condensation is quite considerable, the cylinder areas being represented approximately by the lines MG and EG respectively. If this is true for compounds, it certainly is true for triples.

The saving due to reduction of range of temperature has been proven beyond doubt, and the only question seems to be, "What is the best method of dividing the range between two or more cylinders?" Some say "Equal ranges," and some say "Unequal ranges." The question of superheat comes in, to further increase the difficulty of deciding upon the proper ranges of temperature.

The saving due to steam jackets and superheaters seems to be more on account of increased reëvaporation rather than to reduction of initial condensation. It is probable that the initial condensation is somewhat reduced, but the reëvaporation is certainly increased.

In some tests of compound engines of Mr. Rockwood's design, at the Grosvenordale Mills, several records of less than 13 pounds of water per indicated horse-power per hour were made, one test showing less than 12 pounds. The steam pressure was 150 pounds, and the vacuum 26½ inches.

About the same economy was obtained from a Leavitt pumping engine at Louisville, Ky. This engine had 150 pounds of steam and 27½ inches vacuum in the low-pressure cylinder. The ratio of cylinder was 4 to 1. The stroke of this engine was 10 feet, and the piston speed 370 feet.

From these comparisons it seems probable that a compound having large cylinder ratio and drop, under as favorable conditions as the Leavitt engine, will appreciably reduce the water rate of that engine, which is considerably in the lead of all other

compound engines in which expansion is carried to the line of back pressure in high-pressure cylinders.

It seems, therefore, fairly well settled that Mr. Rockwood, by good engineering, has produced record-breaking compounds. He has not only succeeded in obtaining a record of less than 12 pounds of water per horse-power per hour, in one engine, but has obtained considerably less than 13 pounds in a number of engines, and these records seem to place his engines in a class by themselves.

In connection with large cylinder ratios, I would like to call

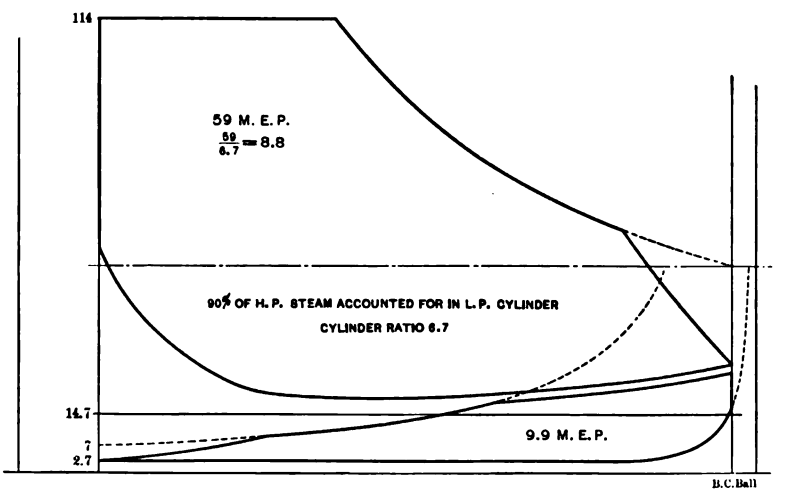


FIG. 344.

your attention to some cards which were loaned to me by the American Engine Company. These are cards from which two engines were designed. These engines are of the style recently built by that company, in which one valve controls the steam for both cylinders.

The first card, Fig. 344, is for 110 pounds boiler pressure, and is being built to run their shop. When it is completed, which will be very soon, a series of tests will be conducted, and it is quite possible that they may throw some light on the subject of cylinder proportions.

In these diagrams, I desire to call your attention to the difference it would make by leaving out of consideration the compression curve.

The diagrams shown in Fig. 345 are for an engine which will have 180 pounds initial pressure and a vacuum of 26 inches. The ratio of expansion of the engine will be about 21, which is rather high for a single-valve engine of moderate clearance. These cards give a cylinder ratio of $8\frac{8}{10}$.

Mr. Rockwood.—When you say "it gives," you mean, don't you, that you select that cylinder ratio?

Mr. Ball.—I mean that, assuming an expansion to 8 pounds absolute, and terminal drop in the high-pressure cylinder of 25 pounds, which is the amount the designer decided upon in this

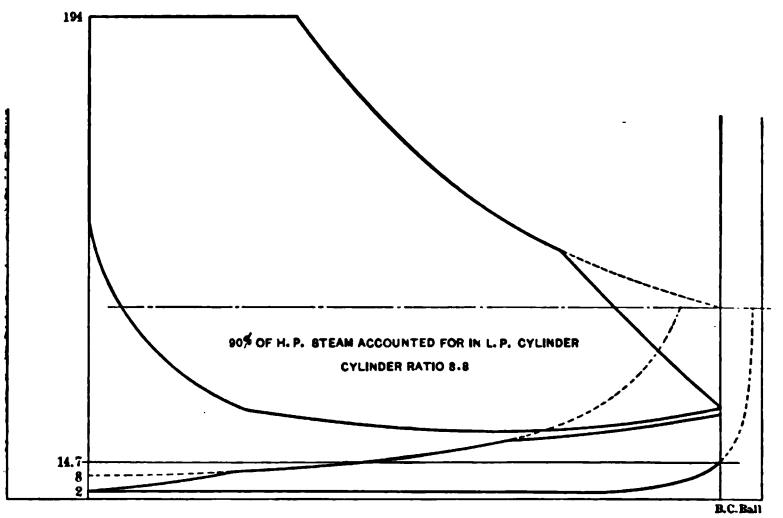


FIG. 345.

case, "it gives" that ratio. It is possible, of course, to get the same number of expansions with a smaller cylinder ratio and no "drop," by cutting off earlier in the stroke, in each cylinder.

In a paper by Professor Thurston, entitled "The Steam Engine at the Close of the Nineteenth Century," he records a test of a quadruple-expansion engine which shows a remarkable duty per 1,000 pounds of steam. He lays great stress in this paper on the Carnot cycle, and devotes about three-fourths of his space to the amplification of it, in connection with this engine. The remarkable system of heaters, which contributed greatly to produce the results obtained, seems to warrant this attention.

As I understand the Carnot cycle, it is a fundamental state-

ment that in a perfect heat engine all the heat should be absorbed at one temperature and discharged at another lower temperature. The embodiment of this principle involves expansion to the back-pressure line, but we all know that this does not give practical economy, on account of the condensation.

An examination of the combined diagrams of this engine, Fig. 346, shows an enormous terminal drop in the low-pressure cylinder. This certainly is not in accordance with the Carnot cycle, and I know of no recorded tests to warrant such a great drop as we find here.

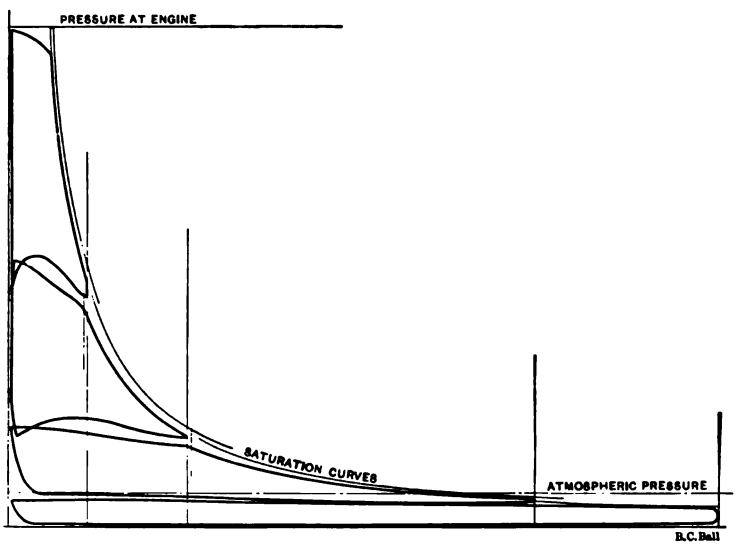


FIG. 346.

Another peculiar feature of this engine is the temperature ranges in the various cylinders, which are, approximately, 57, 62, 56, and 92. I do not believe that the ranges of temperature should necessarily be equal in all cylinders, but this wide variation does not seem consistent, especially as the greatest range is in the cylinder having the greatest surface for condensation.

This engine was tested both with heaters and without, and it developed an indicated horse-power per hour on 12.26 and 11.8 pounds of water, respectively, under the two conditions. It must be understood, of course, that, when running with the heaters, about 10 per cent. of the steam used was turned into the heaters at various stages of its expansion.

Figs. 347 and 348 show diagrams from which I have proportioned triple-expansion cylinders for an engine working under the conditions of this quadruple, which I believe would be more economical than that engine.

In the first place, the expansion is carried to a much lower terminal pressure, giving forty-three expansions, as compared with about twenty-four in the quadruple. The temperature ranges are also more nearly uniform in the different cylinders.

It will be noticed that the terminal drop is only about 3½ pounds in the low-pressure cylinder, and increases to 7 pounds

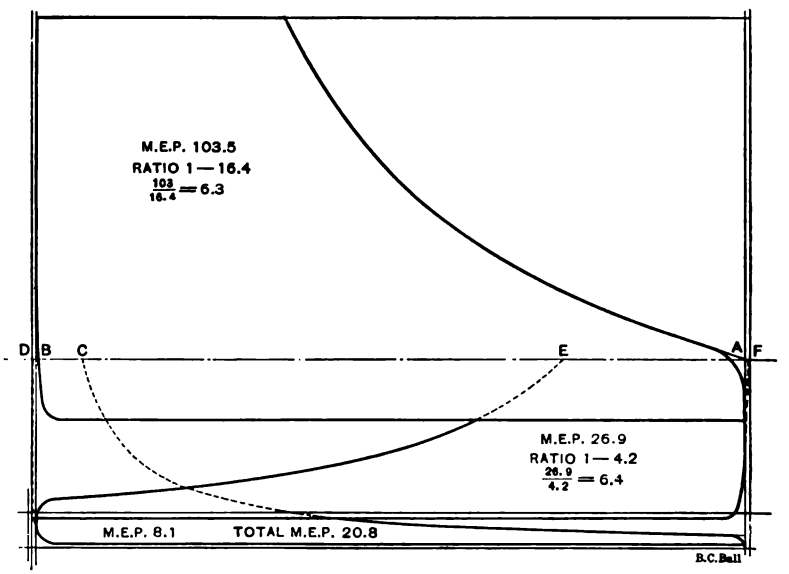


FIG. 347.

in the intermediate-pressure cylinder, and 24 pounds in the high-pessure cylinder. To develop the same power as in the quadruple, the cylinders for the triple would be 19 inches, 37½ inches, and 76½ inches, the cylinder ratios being, high pressure to intermediate pressure, 1 to 3.9; high pressure to low pressure, 1 to 16.4.

Dividing the low-pressure cylinder into two, and placing the high and intermediate cylinders, each tandem, in a low-pressure cylinder would give the same arrangement of cylinders as in the quadruple, and in this case the cylinders would be 19 inches, 37½ inches, and two 54 inches. The steam per indicated horse-power per hour at release in the high-pressure cylinder would be

about 7½ pounds in the triple, compared with about 9½ pounds in the quadruple.

The ranges of temperature in the triple would be somewhat greater than in the quadruple, but the total exposed surfaces for condensation would be less, even with the greater ratio of expansion. Under similar working conditions, I believe that these cylinders would give a greater economy than the quadruple, for the following reasons:

Greater ratio of expansion.

More uniform ranges of temperature.

Less total surface for condensation.

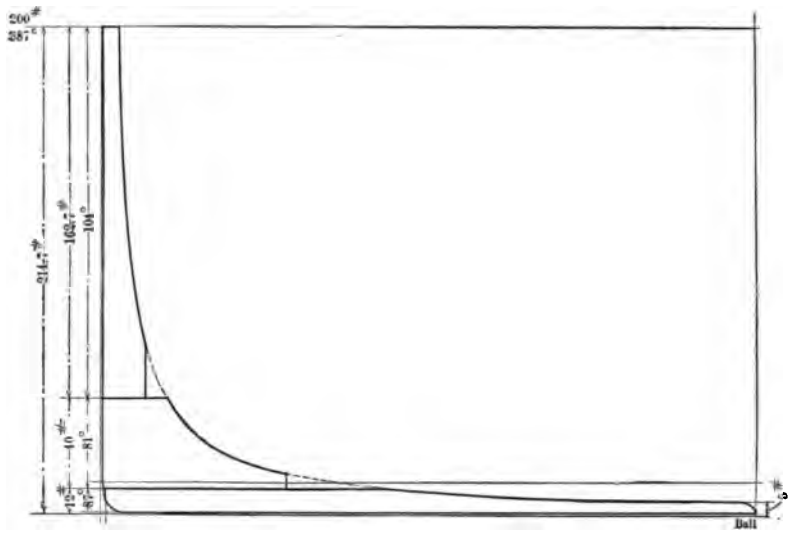


FIG. 348.

APPENDIX.

When this paper was read on its original presentation at the Junior Meeting in New York, March 6, 1900, it elicited some interesting discussion, particularly from a member who had maintained for some years that there was less advantage on the score of economy in triples over compounds with a suitable initial pressure than had heretofore been generally urged. This member was understood to say in the course of his remarks that he had changed his views on this subject. It is hoped that at some later date this contributor will explain his position, and give his reasons for the change, in a paper before the Society.

No. 863.*

A TEST OF A FIFTEEN-MILLION HIGH-DUTY PUMPING ENGINE AT GRAND RAPIDS, MICH.

BY M. E. COOLEY AND F. C. WAGNER
(Members of the Society),
AND BY J. R. ALLEN
(Junior Member of the Society).

THE Grand Rapids Water Works is situated at the intersection of Canal and Coldbrook Streets, in the northern part of the city, and takes its supply from the Grand River. Two conduits, one 3 by 3 feet, the other 4 by 6 feet, conduct the water from an intake crib about 350 feet from the shore to wells just within and under the west wall of the pump house. The smaller conduit leads directly to an 8 by 12-foot oval-shaped well. The larger conduit discharges first into a 35 by 75-foot sand basin and thence into a well 25 feet in diameter, the bottom of which is about 7 feet below low water. The two wells are connected near the bottom.

The city is provided with a low service under a total head of about 165 feet and with a high service under a total head of about 222 feet. The reservoir for the low service and the standpipe for the high service are situated on a bluff about 1,600 feet to the south and 1,100 feet to the east of the pump house. The pumps discharge directly into the service mains, and only the surplus goes to the reservoirs.

The pumping station contains four pumps. Two of these, known as the Butterworth & Lowe pumps, are of the old single steam cylinder, flywheel type. They are still in good condition and are held in reserve for use in emergencies. Originally these pumps were of about 2,500,000 gallons capacity each, and both were connected to the low service. Later, the capacity of one was increased to 5,000,000 and left on the low service, and the other was increased to 3,500,000 and transferred to the high service.

* Presented at the Cincinnati, Ohio, meeting (May, 1900), of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

In 1893 a Gaskill compound pumping engine of 10,000,000 gallons capacity was added to the low service, and in 1895 this was converted into an engine of 8,000,000 gallons capacity and connected to the high service. The Nordberg triple-expansion pumping engine of 15,000,000 gallons capacity was started in connection with the low service, September 10, 1895, and was in nearly continuous operation, as required, up to the time of making the tests, February 5–12, 1896.

The boiler plant contains three Babcock & Wilcox boilers—one of 208 horse-power capacity, erected in 1889; one of 360 horse-power capacity, erected in 1891; and another of 360 horse-power capacity, erected in 1892. A boiler of the marine type, built in 1888, is held in reserve. A 400-horse-power Hoppes live-steam purifier is placed above and between the two 360 horse-power boilers, and is so connected that it can be used with either or both.

The pump house is lighted by an independent electric lighting plant of 150-light capacity, consisting of a Jenny dynamo, running at 1,250 revolutions per minute, driven by a 5½ by 10-inch Buckeye engine.

Description of the Boiler.

The boiler used on the tests was the east one of the Babcock & Wilcox boilers. It is rated at 360 horse-power, and was erected in 1891. It had recently undergone a thorough overhauling and was supposedly in good condition. The brick setting was perfect, and all doors appeared to fit well. The grate was of the ordinary plain, straight, bar pattern. The smoke nozzle, of sheet iron, enters the smoke pipe from the adjacent boiler on the under side, with a simple curved elbow containing a butterfly damper at the boiler opening. The smoke pipe is rectangular in section, and passes horizontally, on a level with the top of the boiler setting, direct to the chimney.

An 8-inch steam pipe starts from the cross pipe connecting the four drums of the boiler, rises 8 feet vertically, passes to the rear 10 feet horizontally; then, with a 10-inch upward jog 3 feet in length, continues horizontally a distance of 20 feet to a cross. The side outlets of this cross connect with branches leading to the other pumps; and the running outlet, reducing to 6 inches, passes a stop valve, and continues 10 feet with a 45-degree turn

to a vertical pipe, dropping 11 feet to the separator immediately above the high-pressure cylinder of the Nordberg engine.

The Hoppes purifier is connected to the 8-inch horizontal pipe above the boiler. A feed pipe connection drops from the Hoppes purifier to the side of the boiler at the front and where it joins the main feed pipe, the connections being so arranged that the purifier can be cut out at will. The blow-off pipes are connected to a main blow-off pipe common to the several boilers. An Albany return steam trap is placed above the boiler and ordinarily discharges directly into the upper drums.

The dimensions of the boiler appear in Table I.

TABLE I.

DIMENSIONS OF BOILER.

Type of boiler: Babcock & Wilcox water tube.	
Number of boilers used	1.
Nominal capacity, horse-power	360.
Number of tubes	180.
Diameter of tubes, inches	4.
Length of tubes, feet	15.67
Inclination of tubes, degrees	15.
Arrangement of tubes: Horizontal rows, staggered vertically.	
Number of steam drums	4.
Diameter of steam drums, inches	30.
Length of steam drums, feet	16.
Diameter of mud drum, inches	14.
Length of mud drum, feet	12.
Number of rear connecting tubes	20.
Diameter of rear connecting tubes, inches	4.
Length of rear connecting tubes, feet	4.
Water space, cubic feet	406.1
Steam space, cubic feet	157.
Heating Surface, computed, square feet:	
Tubes, entire surface	2,953.92
Steam drums, one-half shell	251.33
Rear connecting tubes, entire surface	6.98
Headers, one side	76.58
Total heating surface	3,288.81
Furnace:	
Width, feet	12.
Length, feet	6.
Area, square feet	72.
Grate, plain, straight bar.	
Ratio of air space to grate area	0.50

Draught Area, square feet:	
First passage between tubes	36.44
Second passage between tubes	24.00
Third passage between tubes	21.33
Smoke outlet	14.67
Ratio of heating surface to grate area	45.68
Ratio of grate area to least draught area between tubes	8.38
Ratio of grate area to smoke outlet	4.91
Square feet of heating surface per nominal horse-power	9.14
Chimney:	
Height above grate, feet	101.
Diameter, feet	4.
Draught area, square feet	12.57

Description of the Engine.

The engine is of the horizontal three-crank type with cranks set 120 degrees apart, the sequence being high pressure, low pressure, and intermediate pressure. The three cylinders are placed abreast and are connected to a crankshaft with fly-wheels in the usual manner, except that the intermediate cylinder is provided with a slip crank. The cylinders are 21, 37, and 55 inches in diameter, with a stroke of 48 inches, and are steam jacketed both barrels and heads. Reheating receivers are placed beneath and between the first and second and the second and third cylinders, and a feed-water heater between the third cylinder and the condenser. The arrangement of cylinders, receivers, heater, condenser, and pumps is shown on Figs. 349 and 350.

The steam valves are of the Corliss type and are placed in the main cylinder castings. The cut-off on the high-pressure cylinder is controlled by a governor, while those on the intermediate and low-pressure cylinders are adjustable by hand. The low-pressure cut-off is of an unusual form, the trip being effected by a combination of roller and cam of novel construction.

The condenser is of the jet type and has two single-acting air pumps 17 inches in diameter, with 18-inch stroke. As originally specified, these pumps were 20 inches in diameter, with 12-inch stroke. By the change the volume has been increased 8.37 per cent.; and this, together with the increased stroke, may be regarded as an improvement.

Two single-acting, plunger feed pumps, 4 5 inches in diameter, with 8-inch stroke, are driven from the air-pump rockshaft.

The valves of these pumps are of brass, the design being such that they are readily accessible. The pumps are provided with a by-pass running to the boiler room.

The engine up to this point is a triple-expansion engine of a type that may be used for any purpose whatever. To adapt it to the service of pumping, the piston rods of the three steam cylinders are extended through the heads and coupled direct to the pump plunger rods.

The steam from the boiler, after passing through the 41 feet of 8-inch and 21 feet of 6-inch pipe, enters the top of a vertical separator, 18 inches in diameter and 24 inches in height, made by the Nordberg Manufacturing Company. From the bottom of this separator a 6-inch pipe drops 4.5 feet to the throttle valve, the centre of which is 9 inches above the top of the cylinder.

Passing the first, or high-pressure, cylinder, as shown on Fig. 350, the steam is exhausted through 8.73 feet of 7-inch pipe, containing one elbow, to the first reheating receiver, 30 inches in diameter and 55 inches high, from which it passes through 4.65 feet of 9-inch pipe, containing one elbow, to the second, or intermediate-pressure, cylinder. From the second cylinder the steam is exhausted through 5.28 feet of 12-inch pipe, containing one elbow, to the second reheating receiver, 42 inches in diameter and 60 inches high, from which it passes through 3.53 feet of 12-inch pipe, containing one elbow, to the third, or low-pressure, cylinder. From the third cylinder the steam is exhausted through 8.85 feet of 16-inch pipe, containing one 90-degree and two 45-degree elbows, to the feed-water heater, 42 inches in diameter and 70 inches high.

From the feed-water heater the steam passes through 1.27 feet of 16-inch pipe to the condenser, 28 inches in diameter and 74 inches high. The bottom of the feed-water heater is connected to the condenser by a 2-inch drip.

The separator is drained by a 1-inch pipe, which also serves as the steam supply to the jackets and reheaters. All the water, therefore, which comes to the separator with the steam, passes in order through the high-pressure jacket, first reheater, intermediate-pressure jacket, second reheater, and low-pressure jacket, and, finally, to a drip tank, from which, together with the condensations of the jackets and reheaters, it is returned directly to the boiler by means of a No. 1 Albany return-steam

trap. The pressure in the low-pressure jacket is controlled by a 1-inch G. M. Davis pressure-regulating valve.

Each receiver is provided with a No. 6 Egan trap. In ordinary service these are not required, except in warming up and starting the engine.

A 5-inch injection pipe starts from the larger pump well and passes under the steam cylinders directly to the condenser. A 2-inch force injection from the discharge main is also provided for starting the engine.

The two single-acting, bucket air pumps draw from the condenser without foot valves, and discharge through a 12-inch opening into a hot well, and thence into the main discharge pipe common to all the engines of the pumping plant.

The suction of the two single-acting, plunger feed pumps starts as a 4-inch pipe from the bottom of the hot well, and branches into two 3-inch pipes, one for each pump. In a similar manner the two 3-inch discharge pipes unite in one 4-inch pipe, which enters the bottom of the feed-water heater. From the top of this heater a 2½-inch pipe passes to the Hoppes purifier and to the boilers. A 2-inch all-brass Worthington water meter is placed in the feed-pipe line, about half way to the boilers.

The feed pump is provided with a by-pass running to the boiler room, so that the fireman can control his water supply without leaving the boiler.

The steam piping is covered with 1-inch magnesia sectional covering, except in a few inaccessible places. The steam cylinders are covered with plastic cement and hair felt, and are lagged with planished steel. The heads are provided with polished cast-iron false covers. The receivers, feed-water heater, and their connecting pipes are covered with asbestos cement 2 inches thick. The feed pipe is partly covered between the heater and the meter.

The dimensions of the engine appear in Table II.

TABLE II.

DIMENSIONS OF ENGINE.

Stroke of pistons, nominal, feet	4.0
High-pressure Cylinder:	
Stroke of piston, measured, feet	3.9981
Diameter of piston, inches	21.

Diameter of piston rod, each end, inches	3.625
Net area of piston, square inches	336.0406
Stroke displacement, cubic feet	9.3300
Per cent. of clearance	1.75
Clearance volume, cubic foot	.1633
Total volume of stroke displacement and clearance, cubic feet	9.4933
Intermediate-pressure Cylinder:	
Stroke of piston, measured, feet	8.9958
Diameter of piston, inches	37.
Diameter of piston rod, inches	3.625
Net area of piston, square inches	1064.8916
Stroke displacement, cubic feet	29.5493
Per cent. of clearance	1.75
Clearance volume, cubic foot	.5171
Total volume of stroke displacement and clearance, cubic feet	30.0664
Low-pressure Cylinder:	
Stroke of piston, measured, feet	8.9945
Diameter of piston, inches	55.
Diameter of piston rod, inches	3.625
Net area of piston, square inches	2365.514
Stroke displacement, cubic feet	65.6184
Per cent. of clearance	2.125
Clearance volume, cubic feet	1.3944
Total volume of stroke displacement and clearance, cubic feet	67.013
First Reheating Receiver:	
Diameter, inches	30.
Height between covers, inches	55.
Net volume, deducting reheating tubes, cubic feet	18.44
Volume of pipe connections, cubic feet	4.40
Total effective volume, cubic feet	22.84
Number of reheating tubes	60.
Diameter of reheating tubes (W. I. pipe), inches	1.5
Length of reheating tubes, inches	36.
Internal surface of tubes, including bottom of head, square feet	80.57
External surface of tubes, including top of head, square feet	95.42
Mean of internal and external surfaces, square feet	88.00
Second Reheating Receiver:	
Diameter, inches	42.
Height between covers, inches	60.
Net volume, deducting reheater tubes, cubic feet	40.61
Volume of pipe connections, cubic feet	7.21
Total effective volume, cubic feet	47.82
Number of reheating tubes	114.
Diameter of reheating tubes (W. I. pipe), inches	1.5
Length of reheating tubes, inches	36.
Internal surface of tubes, including bottom of head, square feet	153.03
External surface of tubes including top of head, square feet	180.85
Mean of internal and external surfaces, square feet	166.94

Feed-water Heater:

Diameter, inches	42.
Height between covers, inches	70.
Net volume of steam space, cubic feet	32.29
Number of tubes (brass)	357.
Diameter of tubes, outside, inches	1.0
Length of tubes, inches	50.5
Heating surface, outside of tubes, square feet	393.3
Heating surface, heads, square feet	15.4
Total heating surface, square feet	408.7

Condenser:

Diameter, inches	28.
Height between covers, inches	74.
Distance of scattering plate below top cover, inches	15.
Number of holes in scattering plate	250.
Diameter of holes in scattering plate ($\frac{3}{16}$), inch	0.1875
Volume of steam space, cubic feet	24.05
Ratio of condenser volume to volume of low-pressure cylinder	.366
Diameter of exhaust pipe, inches	16.
Diameter of injection pipe, inches	5.
Area of channel way, 7 x 19, square inches	133.

Air-Pumps, single acting:

Number	2.
Diameter, inches	17.
Stroke, inches	18.
Displacement of one piston, single stroke, cubic feet	2.364
Ratio of displacement of both pumps to volume of low-pressure cylinder	.072
Diameter of discharge pipe, inches	12.

Feed-Pumps, single acting:

Number	2.
Diameter, inches	4.5
Stroke, inches	8.
Displacement of one plunger, single stroke, cubic feet	.0736

Piping, diameters in inches:

High-pressure supply	6.
High-pressure exhaust	7.
Intermediate-pressure supply	9.
Intermediate-pressure exhaust	12.
Low-pressure supply	12.
Low-pressure exhaust	16.
All jacket and reheater pipes	1.

Connecting-Rods:

Length between centres, feet	10
Diameter at crosshead end, inches	9
Diameter at crank end, inches	5.

Diameter of crosshead journal, inches	8.875
Length of crosshead journal, inches	7.
Diameter of high-pressure crank pin, inches	5.625
Diameter of intermediate-pressure crank pin, inches	6.25
Diameter of low-pressure crank pin, inches	5.625
Length of all crank-pin bearings, inches	5.625

Crank-Shafts:

Number, connected by slip crank	2.
Diameter in flywheel, inches	11.
Diameter in cranks, inches	10.625
Diameter in bearings, inches	10.75
Length of shaft, high-pressure end, inches	100.34
Length of shaft, low-pressure end, inches	96.34

Main Bearings:

Number of bearings	4.
Diameter, inches	10.75
Length, inches	18.
Distance between bearings, high-pressure shaft, inches	48.
Distance between bearings, low-pressure shaft, inches	44.
Distance between bearings, adjacent ends of shafts, inches	39.

Flywheels:

Number	2.
Diameter, feet	14.
Depth of rim, inches	12.
Width of rim, inches	10.25
Weight of each wheel, pounds	20,200.

Description of the Pumps.

The pumps are three in number, one to each steam cylinder. They are connected to the steam cylinders by 3-inch stretcher rods, two to each pump. The plungers are of the double-acting, outside-packed type, 17 inches in diameter, with stroke of 48 inches, and are made with rounded ends. The valves are of rubber, and are arranged on cages, one cage containing 30 valves. Each of the three pumps has in each end 90 suction and 90 discharge valves. The total suction-valve area is 18.15 square feet, which exceeds the 14 square feet specified in the instructions to bidders by nearly 30 per cent. The discharge valves have the same area. The ratio of valve area to plunger area is 1.968, which is unusually large.

Each pump has two vertical cylindrical ends, which contain the valves and the stuffing boxes. The vertical cylinders are

connected by two 3-inch stretcher rods, and communicate with each other below the suction valves and above the discharge valves. The tops of the vertical cylinders form air chambers, one for each end of each pump.

Straightway valves are placed in the branches of the suction and discharge mains, so that any pump may be cut out for examination or repairs without shutting down the entire engine.

The arrangement of piping and water passages is shown on Fig. 349, and is as follows: the 36-inch suction main starts from a bell-shaped strainer which rests on the bottom of the larger well. It rises on a curve of 15.75-foot radius and passes around the foundation of the Gaskill engine, on a curve of 13.5-foot radius, to the branch leading to the high-pressure pump, a total distance of 58 feet. It continues across, outside the outer end of the pump foundation, 4 feet 4 inches below the centre line of the pumps, and 9 feet 4½ inches from the centre of the outboard valve chambers. Branch pipes 24 inches in diameter lead to the several pumps, starting from the main on a curve of 5-foot radius.

The branch to the high-pressure pump enters the chamber below the outboard suction valves at an angle of 30 degrees with the axis of the engine. The branches to the intermediate and low-pressure pumps enter at an angle of 45 degrees. The diameter of the suction main is reduced to 24 inches between the branches to the intermediate and low-pressure pumps. A suction air chamber 4 feet in diameter by 12.5 feet in height is connected as close as possible to the end of the suction main beyond the last branch, the connection being 16 inches in diameter.

The chambers below the suction valves are 47 inches inside diameter by 33 inches in height, and are connected by a cylindrical nozzle 24 inches in diameter and 46 inches in length. A low, flat suction air chamber is attached to the top of each of these connecting nozzles by a 10-inch neck. The lower part of this chamber expands in a height of 5 inches from a circular to a rectangular section, and joins the upper part, which is 30 inches wide, 48 inches long, and 14 inches high.

The pump chambers are 47 inches inside diameter and 4 feet 4 inches in height between the suction and discharge valve plates.

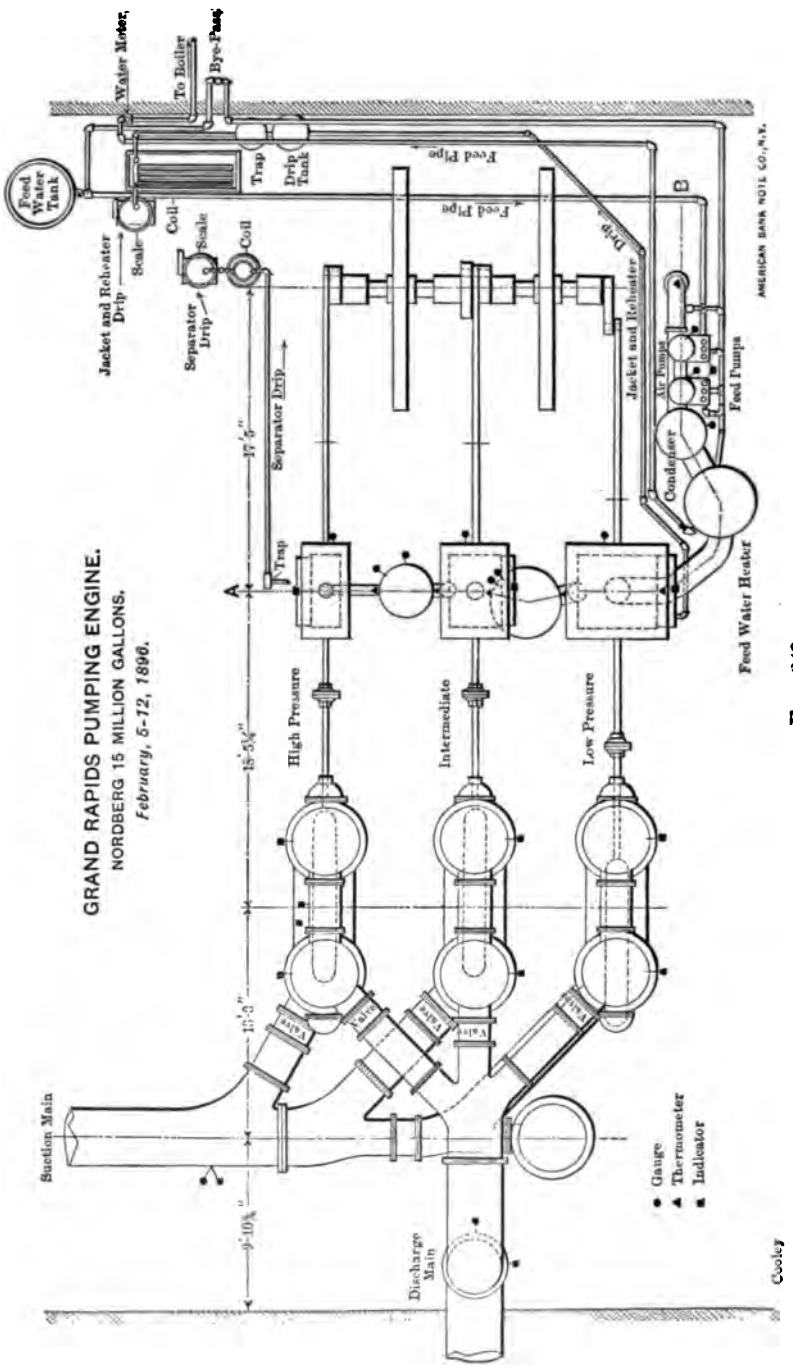

GRAND RAPIDS PUMPING ENGINE.
NORDBERG 15 MILLION GALLONS.
February, 5-12, 1890.
Water Motor
To Boiler
Bye-Pass
Feed Water Tank
Trap
Drip Tank
Feed Pipe
Jacket and Reheater Drip
Scale
Coil
Separator Drip
Drip
Jacket and Reheater
Air Pumps
Condenser
Feed Pumps
Feed Water Heater
Separator Drip
Trap
High Pressure
Intermediate
Low Pressure
Valve
Suction Main
Discharge Main
Gauge
Thermometer
Indicator
Cooley
AMERICAN BANK NOTE CO.,N.Y.

Fig. 349.

The valves are placed on the top and sides of the cages, which rest on the valve plates, three cages on each plate.

The delivery chambers are 47 inches inside diameter and 9 feet 5 inches in height to the inside of the dome-shaped top. These chambers are connected by a 20-inch nozzle at a height of 38 inches above the top valve plate, or 5 feet 4 inches above the centre line of the pump.

The inboard end therefore receives water through the chamber below the outboard suction valves and delivers through the chamber above the outboard discharge valves.

A 20-inch discharge pipe leaves each pump in a horizontal plane 5 feet 4 inches above the centre line of the plungers; those from the high and low pressure pumps make an angle of 45 degrees with the axis of the engine. These pipes unite in a 36-inch discharge main at a horizontal distance of 8 feet 6 inches from the outboard intermediate pump chamber. Beyond the junction the main drops on a curve of 6-foot radius to a vertical portion 43 inches in length, and then with a reverse curve of 6-foot radius passes through the outer wall of the engine room. The length from the junction of the branches to the end of the lower curve is 24.6 feet.

The tops of the discharge air chambers are connected by a system of equalizing pipes of $\frac{1}{2}$-inch diameter; and when required, air is supplied to the chambers through these pipes by means of a Westinghouse air pump. The individual suction air chambers between the pump ends and the large suction air chamber are also connected by a system of equalizing pipes $2\frac{1}{2}$ inches in diameter. The main suction air chamber is connected by a $\frac{1}{2}$-inch pipe to the condenser, so that the height of water in this chamber can be increased at any time if desired. Each end of the pump cylinders is provided with an air-check valve to admit air for cushioning purposes as may be found necessary.

The dimensions of the pumps and water passages appear in Table III.

TABLE III.

DIMENSIONS OF PUMPS.

Stroke of plungers, nominal, inches	48.
Diameter of plungers, nominal, inches	17
Diameter of plunger rods, inches	3.625

High-pressure Plunger:	
Stroke, actual, feet	3.9981
Diameter, actual, inches	16.987
Area, square inches	226.497
Stroke displacement, crank end, cubic feet	6.0020
Stroke displacement, head end, cubic feet	6.2886
Total stroke displacement for one revolution, cubic feet	12.2906
Total stroke displacement for one revolution, gallons	91.9400
Intermediate-pressure Plunger:	
Stroke, actual, feet	3.9958
Diameter, actual, inches	16.9839
Area, square inches	226.5500
Stroke displacement, crank end, cubic feet	6.0001
Stroke displacement, head end, cubic feet	6.2864
Total stroke displacement for one revolution, cubic feet	12.2865
Total stroke displacement for one revolution, gallons	91.9090
Low-pressure Plunger:	
Stroke, actual, feet	3.9945
Diameter, actual, inches	16.9839
Area, square inches	226.5500
Stroke displacement, crank end, cubic feet	5.9931
Stroke displacement, head end, cubic feet	6.2844
Total stroke displacement for one revolution, cubic feet	12.2825
Total stroke displacement for one revolution, gallons	91.879
Total displacement per revolution, three pumps, cubic feet	36.8596
Total displacement per revolution, three pumps, gallons	275.7280
Valves:	
Style, solid rubber valve with brass seat and guard. Arrangement, on sides and top of cages.	
Number of valves on each cage	30.
Number of cages in each set	3.
Number of suction valves in each end of one pump	90.
Number of discharge valves in each end of one pump	90.
Total number of suction valves in three pumps	540.
Total number of discharge valves in three pumps	540.
Diameter of valves, inches	3.5
Thickness of valve, inches	0.875
Weight of one valve, pounds	0.48
Area of clear opening through valve seat, square inches	4.84
Lift of valve, inches	0.5
Area of cylindrical opening under valve when open, square inches	5.50
Total area through valve seats in one set, square inches	435.60
Total area through valve seats of all suction valves, square inches	2,613.60
Total area through valve seats of all suction valves, square feet	18.15
Total area through valve seats of all discharge valves, square feet	18.15
Ratio of area through valve seats to plunger area	1.968
Suction Main:	
Length from bottom of well to branch to high-pressure pump, feet	58.
Diameter of suction main, inches	36.25

Area of suction main, square inches	1,032.06
Length of high-pressure branch to centre of outboard pump chamber, feet	10.82
Diameter of high-pressure branch, inches	24.
Distance along suction main from high-pressure branch to intermediate branch, feet	4.80
Length of intermediate branch to centre of outboard pump chamber, feet	13.09
Diameter of intermediate branch, inches	24.
Length of low-pressure branch to centre of outboard pump chamber, feet	21.68
Diameter of low-pressure branch, inches	24.
Area of each branch suction pipe, square inches	452.39

Discharge Main:

Diameter of discharge main, inches	36.
Area of discharge main, square inches	1,017.88
Diameter of branch discharge pipes, inches	20.
Area of branch discharge pipes, square inches	314.16
Length of high-pressure branch from centre of outboard pump chamber, feet	12.40
Length of intermediate branch from centre of outboard pump chamber, feet	8.50
Length of low-pressure branch from centre of outboard pump chamber, feet	11.90
Length of discharge main from junction of branches to end of lower curve outside of pump house, feet	24.60

Suction Air Chamber on Suction Main:

Diameter, inches	48.
Height over all, feet	12.50
Volume, total, cubic feet	147.70
Volume above approximate water level, cubic feet	92.15

Discharge Air Chambers:

Number	6.
Diameter, inches	47.
Height above discharge valve plate, feet	9.40
Volume of each chamber, total, cubic feet	105.20
Volume above top of delivery pipe, cubic feet	56.90
Distance of topmost discharge valve seat above centre of plunger, inches	41.50
Distance of topmost suction valve seat below centre of plunger, inches	12.50
Distance between centres of inboard and outboard pump chambers, feet	7.75
Distance between centre lines of high-pressure and intermediate pumps, inches	105.
Distance between centre lines of intermediate and low-pressure pumps, inches	101.

Preparations for the Tests.

A few days prior to the tests the boiler had been cleaned and put in good order, and preparations made for weighing the feed water, jacket, and separator drips, and for securing other necessary data.

For the feed water a tank holding about 1,200 pounds was placed on a platform scale in the engine room. The water from this tank was discharged into a second tank of about the same size, placed in the basement, and connected to the suction of the engine feed pumps by an independent 2-inch pipe. The suction pipe from the hot well was disconnected and closed with a blank flange. The 2½-inch discharge pipe between the heater and the meter was disconnected from all other pipes. An independent 2-inch pipe led from the meter to the front of the boiler, where it joined the boiler feed pipe. All connections to the purifier and elsewhere were broken, so that the water passed directly from the weighing tank to the boiler.

A few hours before the test began the drip connection between the feed-water heater and the condenser was broken, and the heater when subjected to a water pressure of 95 pounds per square inch was found to be perfectly tight. This test was repeated at the close of the half-speed test, with the same result.

The drip from the separator was piped to a small G. M. Davis trap which discharged into a cooling coil in a barrel filled with running water. It was then delivered into a second barrel on a platform scale and weighed. The drip pipe was covered from the separator to the trap, but the trap itself was not covered.

The steam for the jackets and reheaters was taken from the main steam pipe between the separator and the throttle. The condensation passed from the drip tank through a No. 5 Nason pot trap to a box coil in a tank provided with cooling water, thence to a barrel on a platform scale for weighing. Owing to the sequence of the jacket and reheater connections it was impossible to separate the jacket and reheater condensations so as to weigh them independently. The receiver traps were cut out and their discharge pipes exposed to sight. All jacket and reheater piping was disconnected from other piping

and was covered, except in a few inaccessible places. The drip well was also covered, but the pot trap was not covered.

The boiler was completely isolated by disconnecting or closing off with blank flanges the surface and bottom blow pipes and other connections common to several boilers. No valves whatever were trusted to be tight unless the pipe was disconnected so that a leak could be detected.

The steam pipe was completely separated from all other pipes, blank flanges being used where the joints could not be broken.

The pump valves were carefully examined by Chief Engineer Bates, January 30th, and reported by him to be in good condition. They were again examined at the close of the tests, by Mr. Allen, who found 129 broken springs, 84 on the suction valves and 45 on the discharge valves. The springs were of volute form and made of No. 12 brass wire. Those broken were badly worn. The action of the valves did not appear to be seriously affected by the broken springs. The plungers were highly polished, and their packings had been carefully adjusted so as to reduce the friction to a minimum.

The steam valves and pistons had not been examined since the engine was started, September 10, 1895. Their actual condition was therefore not known.

The condenser, air pumps, and feed pumps were examined a few hours before the test. A few of the condenser valves were found curled slightly and were inverted.

Apparatus Used on the Tests.

The locations of instruments and of their connections are shown in Figs. 349 and 350.

The regular engine gauge board contains the following instruments: steam gauge connected to the main steam pipe, where it reduces from 8 to 6 inches; first receiver gauge; second receiver gauge; first reheater gauge; second reheater gauge; high-pressure jacket gauge; intermediate-pressure jacket gauge; low-pressure jacket gauge; vacuum gauge; water gauge, connected to discharge main; suction gauge, connected to suction main; and a revolution counter. The second receiver gauge was removed to the basement and connected so as to eliminate any error due to the uncertainty of its water column,

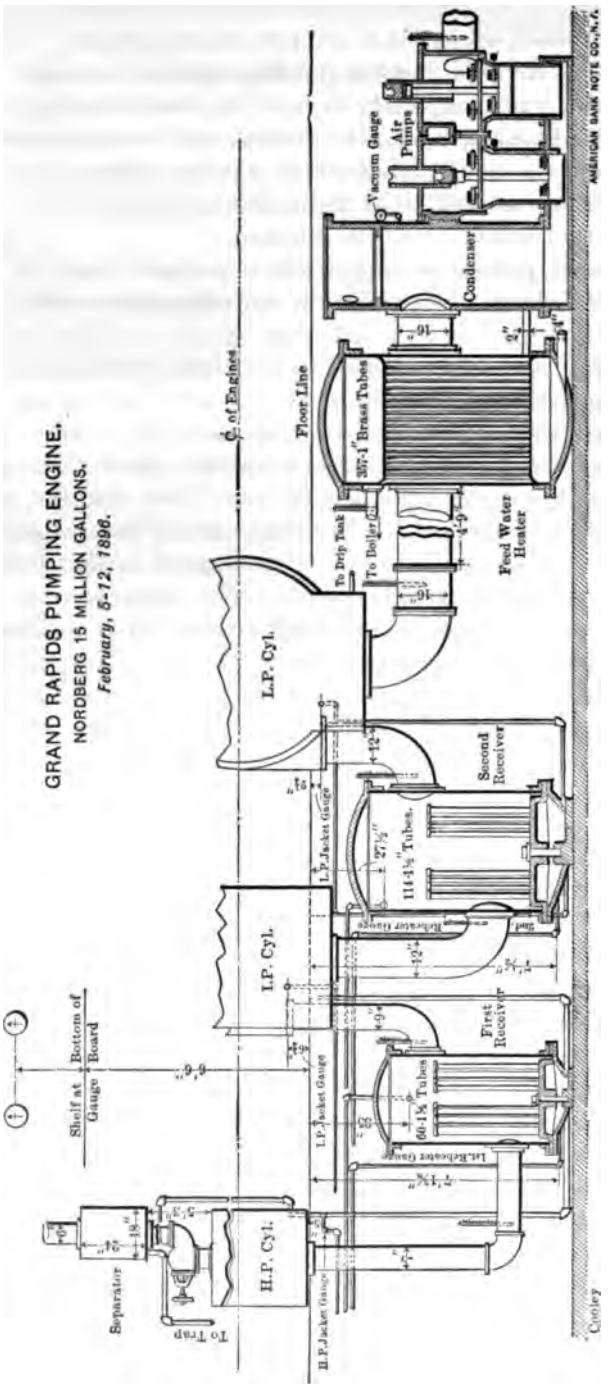

GRAND RAPIDS PUMPING ENGINE.
NORDBERG 15 MILLION GALLONS.
February, 5-12, 1896.
Floor Line
℄ of Engines
L.P. Cyl.
L.P. Cyl.
H.P. Cyl.
Separator
To Trap
Shelf at Gauge
Bottom of Board
Vacuum Gauge
Air Pumps
Condenser
357-1" Brass Tubes
To Drip Tank
To Boiler
Feed Water Heater
Second Receiver
114-1½" Tubes.
First Receiver
60-1½" Tubes
L.P. Jacket Gauge
H.P. Jacket Gauge
Reheater Gauge
Cooley
AMERICAN BANK NOTE CO., N.Y.

FIG. 350.

as its readings were near atmospheric pressure. The suction gauge was disconnected at the suction main in the basement and another gauge substituted. The gauge-board counter stopped for about 13 minutes at 7 P.M., February 6th. A second counter was then attached directly to the engine. The boiler was provided with a second gauge placed just above the furnace doors. Additional gauges were also connected at the following places: steam pipe at the throttle valve, condenser in the basement, and discharge main 14 feet beyond the junction of the branches from the pumps.

A float gauge is used ordinarily to measure both the height of water in the well and the suction lift. This consists of an air-tight vessel guided by vertical ways and connected to one end of a flexible wire cord which passes over an overhead pulley and carries a counterweight on the other end. A pointer attached to one part of the cord indicates on a scale graduated in feet and tenths of a foot the height of water in the well, and a similar pointer on the other part indicates the suction lift. The gauge worked smoothly and accurately.

A single indicator was used on each cylinder. The indicator connections were provided with angle valves at each end, but without three-way cocks. Originally indicators were attached to the water cylinders in the same way. The water hammer in the long connections was so severe, however, that they were abandoned, and the indicators attached directly to each end. Indicators were also used on the air pumps, feed pumps, and on the suction and discharge mains. The motions for the indicators were obtained by pantographs attached to the coupling joining the piston and plunger rods. Cord was used for all indicators during the first part of the test, but as the cords on the water cylinders were long, they were replaced by wire during the latter part of the test.

The quality of the steam was determined by the heat gauge portion of the Barrus universal calorimeter, placed between the separator and the throttle valve.

Thermometers inserted in mercury wells were placed in the following pipes: high-pressure exhaust, first receiver, intermediate-pressure exhaust, second receiver, low-pressure exhaust, condenser discharge, feed water at heater, feed water at meter, and feed water at boiler. The temperature of the feed water at the tank was determined by a thermometer immersed

in the water. The temperature of the water pumped and of the injection water were considered to be the same as that supplied to the feed-water tank, since the latter was drawn directly from the discharge main in the pump house. The water pumped was very nearly at the freezing point, as the river contained considerable moving ice. Other thermometers were used to determine the temperatures of the engine room, boiler room, and external air. A Green pyrometer was inserted in the smoke nozzle, close to the boiler. The atmospheric pressure was determined by an aneroid barometer.

A gas meter was attached to each pump to measure the amount of air admitted through the air checks. The data obtained was not complete, however, as some of the air checks were not connected to the meters.

Calibration of Instruments.

All instruments used in connection with the tests were carefully compared with the standards of the Engineering Laboratory of the University of Michigan. The gauges at the boiler, the engine, and the discharge main were compared daily with a standard. Levels were taken with a surveyor's level, by the assistant city engineer, to determine the suction lift and the corrections for the water columns of all gauges, and of the indicators used on the pumps.

The scales used to weigh the feed water, jacket discharge, and separator drip were tested with standard weights both before and after the tests. The coal scale was tested with standard weights during the third day of the first test. The indicator springs were tested at the temperature at which they were used. The thermometers were very carefully compared with calibrated standards manufactured by H. J. Green. The standards were immersed in deep cups to the reading, while the thermometers used were immersed to the same depth as during the tests.

The testing apparatus used for high temperatures consists of a 9-inch pipe about 24 inches long, capped at the lower end, the top being closed with a blind flange. Four thermometer cups of different lengths are screwed into the blind flange. A sensitive gauge is connected to the apparatus. A $\frac{1}{2}$-inch steam pipe enters through the bottom, and is closed inside with a cap containing six $\frac{1}{8}$-inch radial holes. The discharge pipe starts $1\frac{1}{2}$ inches above the bottom, so that the vessel always contains a

small quantity of water. The entering steam passes through this water, and is thus prevented from superheating by reduction of pressure. The pressure is easily controlled at any desired point by two valves, one on the supply, the other on the discharge. The results obtained with this apparatus showed a very close agreement between the readings of the standard thermometer and the temperature corresponding to the pressure.

The corrections for instruments appear in the accompanying Table IV. Particular attention is directed to the instrumental corrections, which in some cases, even with the better grade of instruments, were found to be large. It is apparent from this that it is unsafe, in work desired to be accurate, to trust entirely to the reputation of the instrument maker. The plus and minus signs indicate that the corrections are to be added or subtracted to the observed reading.

TABLE IV.

CORRECTIONS FOR INSTRUMENTS.

	Instrumental Correction.	Correction for Position.	Total Correction.
Gauges Used on Duty Tests. Pounds per square inch :			
1. Steam gauge, boiler	0.55	−3.20	−2.65
2. Steam gauge, gauge board	−5.90	−6.62	−12.52
3. Steam gauge, engine, first three days	2.86	−0.85	2.01
4. Steam gauge, engine, after first three days	−2.00	−0.85	−2.85
5. First receiver gauge	−0.95	6.42	5.47
6. Second receiver gauge	0.00	0.00	0.00
7. High-pressure jacket gauge	−2.60	4.76	2.16
8. Intermediate-pressure jacket gauge	−3.10	4.36	1.26
9. Low-pressure jacket gauge	−0.50	4.64	4.14
10. First reheater gauge	−2.30	6.79	4.49
11. Second reheater gauge	−1.05	6.71	5.66
12. Vacuum gauge at condenser, inches	0.00	0.00	0.00
13. Water-pressure gauge, gauge board	−1.13	3.22	2.09
14. Water-pressure gauge, at discharge main	1.51	0.00	1.51
15. Suction gauge at suction main, inches	−0.29	3.84	3.55
16. Float, to centre of gauge on discharge main, feet	−0.19	2.00	1.81
Indicator Springs Used on Duty Tests. Pounds per square inch :			
17. High-pressure steam cylinder, 80-pound	−2.01	0 00	−2.01
18. Intermediate steam cylinder, 30-pound	−0.38	0.00	−0.38
19. Low-pressure steam cylinder, 12-pound	0.62	0.00	0.62
20. Inboard end of pumps, 100-pound	12.99	0.00	12 99
21. Outboard end of pumps, 80-pound	4.32	0.00	4.32

TABLE IV.—*Continued.*

	Instrumental Correction.	Correction for Position.	Total Correction.
Indicator Springs Used on Friction Tests. Pounds per square inch:			
22. High-pressure pump, inboard, 100-pound	13.40	−2.40	11.00
23. High-pressure pump, outboard, 80-pound	3.63	−2 41	1.22
24. Discharge air chamber, 60-pound	0.60	0.00	0.60
25. Suction main, 10-pound suction	−0.13	0.00	−0.13
26. High-pressure pump, inboard, 10-pound suction	−0.38	−2.44	−2.82
27. High-pressure pump, outboard, 10-pound suction	−0.38	−2.45	−2.83
28. Intermediate pump, inboard, 10-pound suction	−0.38	−2.45	−2.83
29. Intermediate pump, outboard, 10-pound suction	−0.38	−2.45	−2.83
30. Low-pressure pump, inboard, 10-pound suction	−0.38	−2.45	−2.83
31. Low-pressure pump, outboard, 10-pound suction	−0.38	−2.42	−2.80
Imported Thermometers Used on Duty Tests. A and B, paper scale; C, all glass; degrees Fahr.:			
32. B-12, at 275 degrees, high-pressure exhaust			4.00
33. B-3, at 235 degrees, first receiver			3.25
34. B-6, at 215 degrees, intermediate exhaust			2.50
35. B-11, at 215 degrees, intermediate exhaust			0.90
36. B-2, at 235 degrees, second receiver			1.26
37. B-11, at 120 degrees, low-pressure exhaust			−0.40
38. B-1, at 120 degrees, low-pressure exhaust			−0.60
39. A-6, at 116 degrees, feed water at boiler			−2.13
40. C-4, at 117 degrees, feed water at meter			−1.68
41. A-2, at 117 degrees, feed water at heater			−1.53
42. C-5, at 117 degrees, feed water at heater			−2.27
43. A-3, at 33 degrees, feed water at tank			0.60
44. B-7, at 90 degrees, discharge water			−0.90
45. B-4, at 275 degrees, calorimeter			3.35
46. B-4, at 295 degrees, calorimeter			4.20
47. B-4, at 345 degrees, calorimeter			7.00
48. B-5, at 275 degrees, calorimeter			2.25
49. B-5, at 295 degrees, calorimeter			2.85
50. B-5, at 345 degrees, calorimeter			5.60
H. J. Green's Thermometers Used on Duty Tests. All glass; degrees Fahr.:			
51. No. 7687, at 70 degrees, used for comparison			−0.50
52. No. 7687, at 120 degrees, low-pressure exhaust			−1.13
53. No. 7687, at 235 degrees, second receiver			1.00
54. No. 7687, at 275 degrees, high-pressure exhaust			2.50
55. No. 7687, at 295 degrees, calorimeter			2.50
56. No. 7687, at 345 degrees, calorimeter			5.55
57. No. 5373, at 235 degrees, second receiver			−1.40
58. No. 5373, at 275 degrees, high-pressure exhaust			0.20
59. No. 5373, at 295 degrees, calorimeter			0.70
60. No. 5373, at 345 degrees, calorimeter			2.50
61. No. 5375, at 275 degrees, high-pressure exhaust			0.00
62. No. 5375, at 295 degrees, calorimeter			0.70

Frequency of Observations.

Observations were taken every thirty minutes as follows: Steam pressures at boiler, in steam pipe by gauge on gauge board, in steam pipe by gauge at engine, in first receiver, in second receiver, in first reheater, in second reheater, in high-pressure jacket, in intermediate-pressure jacket, in low-pressure jacket; water pressures in discharge main, by gauge at main, by gauge on gauge board; vacuum in condenser, in suction main; float gauge; barometer; draught gauge; temperatures of high-pressure exhaust in first receiver, of intermediate exhaust in second receiver, of low-pressure exhaust, of feed water at boiler, of feed water at meter, of feed water at heater, of feed water at tank, of discharge from air pumps, of engine room, of boiler room, of external air, of flue gases; water level in boiler; revolutions by counter on gauge board, by counter on floor, as counted; feed-water meter; indicator diagrams from steam cylinders; drip from separator; drip from jackets and reheaters.

The feed water was weighed continuously, the level of the water in the lower tank being brought to a fixed point at the end of each day. The coal was weighed out at irregular intervals and dumped upon the fire-room floor. Care was taken to obtain accurately the amount fired in each twenty-four hours of the full-speed test. The ashes were hauled and weighed at the end of each day of the full-speed test.

Two sets of indicator cards thirty minutes apart were taken from each pump every three hours, the indicators being transferred from one pump to another every hour. Indicator cards were taken from the air pumps and feed pumps for a short time on the fifth day of the full-speed test. Simultaneous cards to determine the friction of the discharge valves were taken in the high-pressure pump and in the discharge main for a short time during the full-speed test. Simultaneous cards to determine the friction of the suction valves were taken in each of the pumps and in the suction main for a short time during each of the three tests.

Calorimeter determinations were made at different times during the tests, readings being taken every five minutes for periods of from one to four hours.

The gas meters attached to the air checks on the pumps were read every four hours.

Auxiliary Tests.

Leakage and Radiation.—A leakage and radiation test was made Tuesday, February 4th, before the first or full-speed test, to determine the leakage of the boiler and the loss of heat by radiation from the piping and engine while at rest. This test began at 3 P.M., and ended at 6 P.M.; but owing to a slight leak at one of the safety valves, and also at the engine throttle valve, other tests were made at the close of the last or half-speed test, February 12th, 13th, 14th. At this time two tests were made—one of 8.25 hours' duration, between 11.30 A.M. and 7.45 P.M., February 12th, to determine the leakage and radiation losses together; the other, of 14.67 hours' duration, between 2.20 P.M., February 13th, and 5 A.M., February 14th, to determine the boiler leakage alone. In the combined leakage and radiation test the throttle valve was found to be leaking again, but in the boiler leakage test the stop valve in the horizontal part of the steam pipe midway between the boiler and engine was closed, and a drip between this valve and the engine left open. The stop valve was tight, and all condensation in the boiler end of the steam pipe returned directly back to the boiler. The water supplied to the boiler to make up the loss was weighed and pumped in by an auxiliary pump operated with steam from a separate boiler. The water was pumped into the boiler slowly, especially during the boiler leakage test, so as to keep the water level nearly constant, and the fire was manipulated so as to maintain a practically uniform steam pressure. No coal was fired for the half hour preceding the beginning and end of the tests, and all doors were closed for fifteen minutes preceding the readings of the water levels. This care was found to be necessary, owing to variations in water level which could be produced by even slight changes at the furnace. A difference in water level of 1 inch at 125 pounds steam pressure at the height observed is equivalent to approximately 720 pounds.

Table V. contains the results of the boiler leakage test, from which it appears that the boiler leaked 279.1 pounds per hour.

TABLE V.

LEAKAGE OF BOILER.

1. Duration of test, hours	14.67
2. Average boiler pressure, gauge, pounds per square inch	123.25
3. Height of water at beginning and end of test, inches	7.93
4. Total water pumped to boiler, pounds	4,110.
5. Total leakage caught and weighed, pounds	18.
6. Net leakage from boiler, pounds	4,092.
7. Net leakage from boiler per hour, pounds	279.10

Table VI. contains the results of the radiation tests, showing the weights of water discharged from the separator and from the jackets and reheaters when the engine was at rest. The weight of water caught from the separator was 103.08 pounds per hour on February 4th, and 63.97 pounds on February 12th. The weight of water caught from the jackets and reheaters was practically the same on both tests, and was 192.6 pounds per hour.

TABLE VI.

RADIATION LOSSES.

1. Date of test	February 4th	February 12th
2. Duration of test, hours	3.00	8.25
3. Average boiler pressure, gauge, pounds per square inch	123.62	125.85
4. Total water from separator, pounds	309.25	527.75
5. Water from separator per hour, pounds	103.08	63.97
6. Total water from jackets and reheaters, pounds	577.75	1,590.00
7. Water from jackets and reheaters, per hour, pounds	192.58	192.60

Table VII. contains results deduced from the boiler leakage and radiation tests, from which it appears that after all apparent leakages are accounted for, there is still a loss of 149.54 pounds per hour which could not be caught and weighed. The larger part of this is probably due to the leak at the throttle valve. On the radiation test of February 4th the drip from the feed-water heater, before it was subjected to water pressure, was 18.75 pounds per hour. This remained unchanged with the heater under pressure.

During the tests it was observed that the lower flanges of the receivers leaked so as to moisten perceptibly the 2-inch cement covering, and that steam issued from the head-end stuffing box

of the intermediate-pressure cylinder. The radiation from the covered surfaces of the receivers and their connecting pipes would account for approximately 40 pounds per hour. Making allowance for this and for the drip at the feed-water heater, there still remains about 90 pounds per hour to be accounted for by the leaks from the receiver flanges and the intermediate-cylinder stuffing box, and by other leaks not observable. The leak at the throttle would disappear with the engine in operation, and any leaks within the engine itself are properly chargeable to it.

TABLE VII.

LEAKAGE OF ENGINE.

1. Duration of test, hours	8.25
2. Average boiler pressure, gauge, pounds per square inch	125.85
3. Height of water at beginning and end of test, inches	9.00
4. Total water pumped to boiler, pounds	5,770.00
5. Total water from separator, pounds	527.75
6. Total water from jackets and reheaters, pounds	1,590.00
7. Total leakage about engine, caught and weighed, pounds	51.98
8. Total steam used in calibrating calorimeter, pounds	65.00
9. Total leakage from boiler, line 7, Table V., pounds	2,302.57
10. Total water accounted for by weighing, pounds	4,537.30
11. Total water not accounted for by weighing, pounds	1,232.70
12. Water not accounted for by weighing per hour, pounds	149.54

Steam Used for Blowing Flues.—The flues of the boiler were blown twice every day regularly, steam for this purpose being taken from the boiler operating the Nordberg engine. The time required for this purpose was observed, and on February 14th a test was made to ascertain the amount of steam used. A barrel holding about 400 pounds was filled nearly full of water, in which the steam discharged by the flue blower was condensed. Three tests of two minutes each were made and found to agree very closely. The results appear in Table VIII.

TABLE VIII.

STEAM USED FOR BLOWING FLUES.

1. Average weight of steam discharged per minute, pounds	6.43
2. Average time required to blow flues, minutes	11.00
3. Weight of steam used each time, pounds	70.73
4. Weight of steam used each day, pounds	141.46
5. Weight allowed in computing results of duty tests, pounds	140.00

Calibration of Calorimeter.—The calorimeter was tested February 12th, both for radiation and for weight of steam discharged.

The engine being at rest, the instrument was started and read at 2-minute intervals for 24 minutes. The last 8 readings, being practically constant, were selected and averaged. For the weight discharged, a barrel holding about 400 pounds was filled nearly full of water, in which the steam was condensed. Three tests were made, covering a period of 19 minutes, during which the steam was weighed. The results of the radiation and of the weighing tests appear in Table IX.

TABLE IX.

CALIBRATION OF CALORIMETER.

1.	Number of 2-minute readings	8.
2.	Average temperature by upper thermometer, degrees	352.90
3.	Average temperature by lower thermometer, degrees	294.95
4.	Average difference of upper and lower thermometers, degrees	57.95
5.	Computed difference of upper and lower thermometers, degrees	51.50
6.	Correction due to radiation, degrees	6.45
7.	Time during which steam was condensed and weighed, minutes	19.
8.	Average steam pressure, gauge, pounds per square inch	123.87
9.	Total steam discharged, pounds	24.75
10.	Average weight of steam discharged per minute, pounds	1.30

Calorimeter Determinations.—The calorimeter was in use for short periods at different times during the duty tests. The results obtained showed a slight amount of moisture for the first three days, but for each of the other days the steam was dry. The $\frac{1}{2}$-inch connecting pipe was uncovered for a space of about 8 inches next the steam pipe during the first three days. In the computations the steam has been assumed to be dry for the entire time. The results of the calorimeter determinations appear in Table X.

TABLE X.

CALORIMETER DETERMINATIONS.

Number of Test.	Date.	Duration of Test. Hours.	Upper Thermometer T_1.	Lower Thermometer T_2.	Per Cent. of Moisture.
1	Feb. 5	2	349.3	286.0	0.32
2	Feb. 6	1	349.0	287.2	0.26
3	Feb. 6	2	352.0	280.7	0.68
4	Feb. 8	4	349.8	289.5	0.18
5	Feb. 9	2	350.7	293.7	0.00
6	Feb. 10	2	349.8	294.4	0.00
7	Feb. 11	1	350.0	293.7	0.00
8	Feb. 12	1.2	350.6	293.2	0.00

Temperature of Low-pressure Jacket Discharge.—The engine was connected up as in regular service, on February 15th, and a thermometer was placed in the jacket discharge pipe at its entrance to the drip tank. A series of readings of this thermometer and of the low-pressure jacket gauge was taken with the engine in operation. The temperature was found to differ by only one degree from the temperature corresponding to the pressure observed simultaneously at the gauge board. The temperature used in the computations for feed-water correction has, therefore, been assumed to be the same as that corresponding to the pressure in the low-pressure jacket.

Use of Air in Pump Cylinders.—As the speed of the engine was caused to vary somewhat suddenly at times, on account of the elevator service in the city being connected directly to the water mains, it was found necessary to admit more or less air to the water cylinders through the air checks. These checks were used irregularly as occasion demanded. An attempt was made to measure this air by connecting all the checks to a single gas meter. This proved unsatisfactory, and each pump was provided with a separate gas meter; and later the meters were connected to only one end of the high-pressure and intermediate pumps, and to both ends of the low-pressure. While this gave better results, the action of the meters was still unsatisfactory, and the results can only be regarded as approximate. A still better plan would have been to pipe all the checks separately to a common reservoir, and to admit air to this reservoir through a single meter.

It was obvious that at night and on Sunday, when the elevator service was not much in use, less air was required; also that during the tests at reduced speed the air checks were not needed. The elevator service appeared to affect the amount of air used more than did an increase of speed. The test shows the maximum quantity to have been used on Saturday with a plunger speed of 322.6 feet per minute; while on Sunday, with a plunger speed of 335.7 feet, the quantity of air used was only about one-half as great.

The results obtained appear in Table XI., which shows the average quantity of air admitted to the intermediate and low-pressure pumps to have been 0.49 per cent. of their stroke displacement.

No allowance has been made in the computations for the air

used further than to assume that it was amply covered by the 2 per cent. specified in the contract for slip or loss of action.

TABLE XI.

USE OF AIR IN PUMP CYLINDERS.

	High-pressure, Outboard.	Intermediate, Outboard.	Low-pressure, Both Ends.
1. Duration of test, hours	12.	133.12	133.12
2. Average pressure below atmosphere at end of suction stroke, pounds per square inch	-5.0	-2.65	-3.18
3. Barometer, pounds per square inch	14.29	14.33	14.33
4. Average absolute pressure at end of suction stroke, pounds per square inch	9.29	11.68	11.15
5. Temperature of air at meter, estimated, degrees	55.	55.	55.
6. Temperature of air in pump, degrees	34.	34.	34.
7. Volume in water cylinder of 1 cubic foot by meter, cubic feet	1.47	1.17	1.23
8. *Volume of Air Per Hour by Meter, Cubic Feet:*			
9. First day—Wednesday	6.7	43.8	31.3
10. Second day—Thursday	.....	42.3	46.8
11. Third day—Friday	.....	91.3	99.2
12. Fourth day—Saturday	.....	120.0	190.5
13. Fifth day—Sunday	.....	75.9	77.6
14. Sixth day—Monday	.....	95.1	97.8
15. Average	.....	78.1	90.5
Volume of Air Per Stroke in Water Cylinder, Cubic Feet:			
16. First day—Wednesday	0.004	0.022	0.017
17. Second day—Thursday	.....	0.021	0.025
18. Third day—Friday	.....	0.045	0.051
19. Fourth day—Saturday	.....	0.058	0.097
20. Fifth day—Sunday	.....	0.035	0.038
21. Sixth day—Monday	.....	0.047	0.051
22. Average	.....	0.038	0.046
23. Stroke displacement, cubic feet	6.285	6.285	12.282
Per Cent of Stroke Displacement:			
24. First day—Wednesday	0.065	0.351	0.135
25. Second day—Thursday	.....	0.340	0.202
26. Third day—Friday	.....	0.717	0.418
27. Fourth day—Saturday	.....	0.926	0.790
28. Fifth day—Sunday	.....	0.568	0.309
29. Sixth day—Monday	.....	0.752	0.415
30. Average	.....	0.608	0.379

Plunger Measurements.—The actual length of stroke of each plunger was carefully measured while the engine was in operation, in the following manner: A $\frac{5}{8}$-inch pin 3 inches long was screwed into one of the bolt-holes used to fasten the indicator

staff to the coupling between piston and plunger rods. A wooden straight-edge was secured between the heads of the steam and water cylinders in line with and just under this pin. Steel triangles were placed on the top edge of the straight edge and adjusted by contact with the pin to the exact length of stroke. The distance on the straight-edge between the triangles gave the length of the stroke plus the diameter of the pin. This distance was measured by a standard steel rule graduated in hundredths of an inch, and the diameter of the pin was obtained by a micrometer caliper.

The diameter of the plungers was measured both by calipers and by a thin steel tape. The measurements obtained with the tape are considered more reliable, and have been used. The thickness of the tape was measured by a micrometer caliper and allowed for. The length of the tape between readings was measured by a standard steel rule. The length of stroke and the diameter of plunger for each pump appear in Table XII.

TABLE XII.

PLUNGER MEASUREMENTS.

Length of Stroke as Measured, feet:	
High-pressure plunger, average of 3 measurements	3.9981
Intermediate-pressure plunger, average of 3 measurements	3.9958
Low-pressure plunger, average of 2 measurements	3.9945
Diameter of Plunger as Measured, inches:	
High-pressure plunger, average of 4 measurements	16.9819
Intermediate-pressure plunger, average of 4 measurements	16.9839
Low-pressure plunger, average of 4 measurements	16.9839

Precautions.

The usual precautions were observed to insure accuracy in the data obtained. At the beginning and end of each test the water was brought to the same level in the lower feed tank and in the boiler. The fire was light, and was manipulated as nearly as possible in the same manner, to avoid inaccuracy in the water level. The ash-pit was cleaned. The coal and ashes were weighed up for each day's run.

All leaks in the piping were carefully noted and entered in the log, not only at the beginning and end, but at frequent intervals during the tests. As far as possible these leaks were caught and weighed.

The more important gauges were compared with a standard

daily. The float-gauge reading was compared with actual measurement at the beginning, middle, and end of the tests. An additional check on the accuracy of the float-gauge readings was obtained by comparison with a mercury column which was connected by independent pipes both to the well and to the condenser. By means of the vacuum in the condenser the pipes could be freed of air and filled with water, so that when connection with the condenser was cut off a perfect water column connected the mercury gauge with the well. This mercury column was also used as a check on the vacuum gauge attached to the condenser.

The gauge-board counter was supplemented by a second counter attached directly to the engine. In addition to this, the revolutions were counted for a period of 5 minutes every half hour.

The union couplings at all gauges were loosened prior to the tests to establish the certainty of the water column corrections to be applied to the gauge readings.

As a check upon the weighings, the feed water was passed through a water meter, which was read at regular intervals.

Personnel.

The tests were conducted by Prof. M. E. Cooley, assisted by Prof. Frank C. Wagner and John R. Allen, M.E. The data were taken by the members of the senior class in mechanical engineering of the University of Michigan, assisted by the Assistant City Engineer, George M. Ames, and Messrs. Redman, Carpenter, Cutcheon, Pearl, and Gray, of the city engineer's staff.

The Nordberg Manufacturing Company was represented by Mr. Bruno Nordberg, who was present during the last three days of the tests, and by R. H. Corbett, erecting engineer, assisted by J. P. Hanson and F. Whitbeck, who were present throughout the tests.

The pumping plant was in charge of Chief Engineer E. A. Bates, who was present during all the tests. He was assisted by Assistant Engineers S. N. Barrows, A. J. Egan, and A. E. Sonnes, Firemen J. Murphy, H. Spears, and M. Noveck, and Coal Passer R. Stewart.

A large part of the computations have been made by Professor Wagner and Mr. Allen, to whom much credit is due for their care and skill in working up the results.

Preliminary Runs.

Short preliminary runs were made by the Nordberg representatives for adjustment of valves and to insure that all parts of the machinery were in good working condition. The first leakage and radiation test was begun at 1 P.M., February 4th, and continued until 6 P.M. The engine was started at 6.30 P.M. and run until 11 P.M., to adjust indicators and to see that all instruments and apparatus worked properly. It was found necessary to change the indicator connections on the pumps, owing to water hammer in the long connections. This necessitated the use of two indicators to each pump, so that with the number of indicators available complete sets of simultaneous cards could not be obtained.

It was also found that the vacuum was not as good as was to be expected. The engine was therefore shut down to change the indicator connections and to overhaul the condenser and the air pumps.

Duration of Tests.

The engine was again started at 3.15 A.M. February 5th, and was not stopped until 10.20 A.M. February 12th.

The official test of 144 hours' duration at full speed began at 6 A.M., February 5th, and ended at 6 A.M., February 11th. The engine was then slowed down, and a test of 12 hours' duration at three-quarters speed begun at 7 A.M. At the conclusion of this test the engine was still further slowed down, and a test at half speed begun at 8 P.M. Soon after the beginning of this test, however, the water backed up in the feed pipe and caused the lower tank to overflow. A second start was therefore made at 9.30 P.M. The half-speed test ended at 9.45 A.M., February 12th, and was of 12.25 hours' duration, the additional 15 minutes being required to bring the water in the boiler down to the same level as at the start.

The second leakage and radiation test was begun at 11.30 A.M., and continued until 7.45 P.M., February 12th, and was of 8.25 hours' duration. The boiler leakage test was begun at 2.20 P.M., February 13th, and continued until 5 A.M., February 14th, and was of 14.67 hours' duration.

Boiler Test.

As a matter of interest in connection with the engine test it has been thought desirable to include in the report the results obtained from the data secured in the boiler room.

The data were observed during the entire full-speed test, but were not observed completely during the tests at reduced speed. The boiler test, therefore, covers only the six days of the official test.

The fires were handled by the regular firemen of the pumping station, who were instructed to perform their work as in every-day service.

Previous to the test the boiler had been cleaned and put in good order; since which time it had been under steam for a period of about ten days. The condition of the fire at the beginning and end of the test was approximately the same. The flues were blown regularly at 10 A.M. and 10 P.M. The coal and ashes were separated for each day, but not for intermediate periods.

The coal used on the test was reported by Mr. A. Himes, resident agent, as "Linden" lump, furnished by the Worthington Coal and Coke Co., Fairmont, West Virginia, the mines being located 25 or 30 miles east of Fairmont and 14 miles from the "Montana" mines. The coal was taken from a shed, and appeared to be dry.

The evaporation obtained, of 8.15 pounds of water per pound of coal from and at 212 degrees, is not high for the kind of coal used. The results might have been somewhat better with a reduced grate area, as the boiler was only required to work at about 63 per cent. of its rated capacity. They might also have been improved with a different arrangement of the tiling in the boiler. The temperature of the flue gases averaged 583.4 degrees, which, considering the power developed, was very high. In ordinary service, one boiler is used to operate both the Nordberg and the Gaskill engines, and is required to develop more nearly its rated horse-power.

The quality of steam was found from the separator drip corrected for the probable condensation due to radiation from the steam pipe. The outside surface of the steam pipe under the 1-inch magnesia covering was approximately 150 square feet. The moisture obtained in this way was 0.9 per cent. The

method of finding the moisture by passing the entire steam through a separator is regarded as more accurate than by using a sample drawn from the pipe through the usual perforated nipple.

No deduction has been made in the computations for leakage from the boiler in addition to that caught and weighed from the feed pipe, notwithstanding the fact that the greater part of it appeared to be from the hand-hole plates at the end of the tubes. The total leakage averaged 279.1 pounds per hour.

The dimensions of the boiler appear in Table I., and the performance in Table XIII.

TABLE XIII.

PERFORMANCE OF BOILER.

1. Date of test	February 5–11, 1895.
2. Duration of test, hours	144.
Fuel, bituminous coal, "Linden" lump.	
3. Total coal fired, pounds	137,728.
4. Total ashes and clinkers, pounds	10,253
5. Total combustible, pounds	127,475.
6. Per cent. of ashes and clinkers	7.44
Pressures, average:	
7. Steam pressure, gauge, pounds per square inch	124.846
8. Barometer, inches of mercury	29.223
9. Barometer, pounds per square inch	14.333
10. Steam pressure, absolute, pounds per square inch	139.179
11. Draught, inches of water	0.292
Temperatures, average, degrees Fahr.:	
12. Feed water at meter	117.16
13. Feed water at boiler	116.69
14. Flue gases	583.42
15. Fire room	75.66
16. External air	29.97
Water Level in Boiler, above lower guard plate, inches:	
17. Height at beginning of test	9.25
18. Height at end of test	9.25
19. Average height during test	9.37
Feed Water, as weighed, pounds:	
20. Total water weighed to boiler	990,596.25
21. Deduction for leakage	216.
22. Total water entering boiler	990,380.25
23. Drip from separator at engine	12,980.44
24. Condensation in steam pipe (calculated)	4,032.
25. Moisture in steam leaving boiler	8,948.44
26. Per cent. of moisture	0.908
27. Total water actually evaporated	981,431.81

Evaporation, under actual conditions:	
28. Number of pounds of water per pound of coal	7.126
29. Number of pounds of water per pound of combustible	7.699
30. Factor of evaporation	1.1438
Evaporation, from and at 212 degrees Fahr.:	
31. Total number of pounds of water	1,122,562.
32. Number of pounds of water per pound of coal	8.151
33. Number of pounds of water per pound of combustible	8.806
Rate of Combustion, per hour:	
34. Number of pounds of coal burned	956.44
35. Number of pounds of coal burned per square foot of grate area	13.284
36. Number of pounds of coal burned per square foot of heating surface	0.291
Rate of Evaporation, under actual conditions, per hour:	
37. Number of pounds of water evaporated	6,815.5
38. Number of pounds of water evaporated per square foot of grate area	94.66
39. Number of pounds of water evaporated per square foot of heating surface	2.072
Rate of Evaporation, from and at 212 degrees Fahr., per hour:	
40. Number of pounds of water evaporated	7,795.6
41. Number of pounds of water evaporated per square foot of grate area	108.27
42. Number of pounds of water evaporated per square foot of heating surface	2.870
Horse-power:	
43. Number developed (based on 34.5 pounds per hour from and at 212 degrees Fahr.)	225.96
44. Builder's rating	360.
45. Per cent. of rated capacity	62.77

Engine Tests.

The desire expressed by the Board of Public Works to have the engine tested at various speeds, and their hearty coöperation in making very complete preparations for the tests, made it possible to obtain unusually full and complete data on the performance of the engine. In view of this, the data have been worked up in considerable detail in the belief that the results will not only be found acceptable and valuable to the city, but also that they will aid in the development of high-grade pumping machinery.

In order to obtain this data a force of 24 observers, divided into three watches, were employed for the six days of the contract trial.

The engine worked smoothly and well, and gave no trouble except in a single instance. At 4.30 A.M., February 8th, the low-pressure main bearings began to heat. The quarter boxes with which the shaft is fitted enabled the journal to be cooled quickly without slowing the engine, and no further trouble was experienced.

The principal dimensions of the engine appear in Table II. and the performance in Table XIV.

The first six columns contain the results for each day of the full-speed test, the seventh column the average results for the entire test, and the eighth and ninth columns the results of the tests at reduced speeds. The fifth and sixth columns are of special interest in view of the increased speed of the engine in the one, and the increased head in the other. The greater interest, however, attaches to the last three columns, in which are shown the results at three different speeds.

Steam Used by the Engine.—The leakage of the boiler, separator drip, and steam used by the calorimeter, shown in lines 2, 3, and 4, are deducted from the total quantity of water supplied to the boiler, line 1, to determine the steam used by the engine, line 6.

Allowance to Reduce to Contract Conditions.—It was stipulated in the contract that the engine should "develop a duty of 145,000,000 foot-pounds per 1,000 pounds of dry steam supplied to the engine, including all steam necessary to supply the jackets and reheaters, feed pump, and traps. The amount of steam used to be calculated from the amount of feed water supplied to the boiler and evaporated from a temperature of 100 degrees Fahrenheit." The engine is therefore to be credited with an amount of steam equivalent to the heat delivered by the engine to the feed water in excess of 100 degrees Fahrenheit.

Had the jacket and reheater drip, line 9, been discharged into the feed water between the heater and the boiler it would have been possible to determine the actual temperature of the mixture by a short run under normal conditions. This was not possible, however, as in ordinary service the drip discharged from the separator, jackets, and reheaters is returned directly to the boiler by means of an Albany return steam trap, the separator drip passing through the jackets and reheaters. It has, therefore, been necessary to calculate what would have been the average temperature of the feed water, including the

TABLE XIV.

PERFORMANCE OF ENGINE.

Test of February 5–12, 1896.

	First Day.	Second Day.	Third Day.	Fourth Day.	Fifth Day.	Sixth Day.	Average, Six Days.	Three-quarter Speed Test.	One-half Speed Test.
Duration of Test, hours	24	24	24	24	24	24	.....	12	12.25
Steam Used:									
1. Total number pounds water supplied to boiler	161,518.5	157,166.75	162,535.	165,469.	173,180.5	170,726.5	165,099.38	64,742.	43,405.
2. Total number pounds water due to leakage	6,918.96	6,918.96	6,918.96	6,918.96	6,918.96	6,918.96	6,918.96	3,459.48	3,531.55
3. Total number pounds water from separator drip	2,227.00	2,169.44	2,164.75	2,050.50	2,177.0	2,191.75	2,163.41	1,017.25	871.20
4. Total number pounds water discharged by calorimeter	234.	156.	287.3	24.7	292.5	19.5	169.	79.3	92.80
5. Total deductions	9,379.96	9,241.4	9,371.01	8,994.16	9,388.46	9,130.21	9,251.37	4,556.03	4,495.05
6. Total number pounds delivered to the engine	152,138.54	147,922.35	153,163.99	156,474.84	163,792.04	161,596.29	155,848.01	60,185.97	38,909.95
7. Allowance to reduce to contract conditions	5,567.28	5,439.84	5,690.4	5,836.8	6,088.88	5,816.88	5,731.68	2,470.56	1,653.26
8. Total number pounds, net, charged to engine	146,571.26	142,482.51	147,473.59	150,638.04	157,753.16	155,779.31	150,116.33	57,715.41	37,256.69
9. Total number pounds used by jackets and reheaters	21,888.75	21,079.5	21,370.	21,160.25	21,805.	21,328.25	21,438.62	9,068.75	6,962.
10. Per cent. of steam used by jackets and reheaters	14.388	14.250	13.952	13.523	13.312	13.198	13.756	15.068	17.893
11. Quality of steam	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Steam Pressures, Average, Pounds per Square Inch, Gauge:									
12. At boiler	124.61	124.85	124.85	124.89	124.876	125.	124.846		
13. At engine	124.793	124.563	124.235	124.373	124.773	124.503	124.540	124.905	125.738
14. In first receiver	31.001	30.477	30.91	30.94	30.58	33.51	31.236	31.90	31.99
15. In second receiver	.362	.676	.814	.841	.947	2.17	.968	.564	.214
16. In first reheater	102.379	104.199	103.359	102.929	101.659	101.019	102.591	107.379	115.949
17. In second reheater	90.989	93.548	93.167	93.497	91.490	92.507	92.523	100.637	111.967
18. In high-pressure jacket	111.651	112.621	112.021	112.211	110.491	110.411	111.567	114.091	119.451
19. In intermediate jacket	95.076	97.526	96.726	96.056	95.094	95.366	95.974	102.756	110.876
20. In low-pressure jacket	41.212	42.520	42.158	41.601	41.676	41.841	41.850	49.276	57.258

PERFORMANCE OF ENGINE—*Continued.*

	First Day.	Second Day.	Third Day.	Fourth Day.	Fifth Day.	Sixth Day.	Average, Six Days.	Three-quarter Speed Test.	One-half Speed Test.
Barometer:									
21. Height in inches of mercury..	29.132	29.093	29.368	29.379	29.216	29.153	29.223	29.563	29.786
22. Pressure, pounds per sq. in...	14.294	14.275	14.410	14.411	14.333	14.303	14.338	14.51	14.61
Vacuum:									
23. In condenser, inches mercury	25.696	25.64	25.937	25.773	25.625	25.629	25.716	25.92	26.188
24. In condenser, lbs. per sq. in..	12.608	12.581	12.726	12.646	12.573	12.580	12.618	12.722	12.849
Temperatures, Average, Degrees Fahrenheit:									
25. High-pressure exhaust.....	276.02	274.64	275.56	275.71	275.18	279.09	276.036	277.60	277.32
26. In first receiver.....	286.78	286.43	285.42	283.91	282.21	284.34	284.848	289.00	297.03
27. Intermediate exhaust.....	215.68	217.08	217.94	217.65	217.64	221.59	217.930	216.02	215.29
28. In second receiver.....	234.86	234.15	232.73	231.20	229.80	233.29	232.506	241.44	259.34
29. Low-pressure exhaust.....	119.13	119.4	120.57	121.82	120.66	120.006	120.267	119.8	119.7
30. Feed water at boiler.....	116.58	115.72	116.16	117.78	117.24	116.68	116.693		
31. Feed water at meter.....	115.99	116.22	117.15	118.45	117.94	117.24	117.165	118.08	115.85
32. Feed water at heater, as observed	116.43	116.72	117.82	118.95	118.80	117.89	117.770	119.97	117.
33. Feed water cor. for jacket drip	141.036	141.24	141.663	141.832	141.346	140.368	141.247	146.035	150.544
34. Injection water and water pumped..... ...	33.23	33.76	33.87	33.85	33.92	33.87	33.750	33.11	33.64
35. Discharge water, hot well.....	91.59	90.97	88.99	90.54	96.44	92.43	91.826	88.7	88.63
36. Engine-room.....	75.78	76.09	75.78	77.67	74.20	76.70	76.036	72.88	75.54
37. External air.....	29.07	32.52	32.40	26.43	30.86	28.528	29.968		
Revolutions:									
38. Gauge-board counter, reading at beginning.....	1,976,102.	2,032,033.	2,087,368.	2,144,477.	2,202,596.	2,263,128.	2,117,617.	2,321,838.	2,346,431.
39. Gauge-board counter, reading at end.....	2,032,033.	2,087,368.	2,144,477.	2,202,596.	2,263,128.	2,319,850.	2,174,908.	2,343,497.	2,360,432.
40. Gauge-board counter, total number revolutions.....	55,931.	* 55,880.	57,109.	58,119.	60,532.	56,722.	* 57,382.	21,659.	14,001.
41. Gauge-board counter, revolutions per minute.....	38.841	38.805	39.659	40.360	42.036	39.390	39.848	30.082	19.049
42. Floor counter, revolutions per minute.....			39.659	40.360	42.080	39.372		30.083	19.046
43. Revolut'ns per min., as c'nted	38.968	38.975	39.725	40.47	42.104	39.390	39.941		

* 545 revolutions added for slip of counter.

PERFORMANCE OF ENGINE—*Continued.*

	First Day.	Second Day.	Third Day.	Fourth Day.	Fifth Day.	Sixth Day.	Average, Six Days.	Three-quarter Speed Test.	One-half Speed Test.
Indicated Horse-power:									
44. High-pressure cylinder, crank end	72.343	70.477	72.519	73.801	81.297	78.906	74.740	55.016	32.867
45. High-pressure cylinder, head end	73.737	73.496	75.831	77.248	79.962	80.232	76.751	57.595	32.600
46. High-pressure cylinder, total	146.080	143.973	148.350	151.049	161.259	159.138	151.491	112.611	65.467
47. Intermediate cylinder, crank end	74.367	73.217	74.828	76.782	81.528	78.683	75.439	54.919	34.915
48. Intermediate cylinder, head end	74.813	69.541	72.253	72.728	74.962	73.266	74.022	57.677	33.715
49. Intermediate cylinder, total	149.180	142.758	147.081	149.510	156.490	151.949	[149.461	112.596	68.630
50. Low-pressure cylinder, crank end	103.073	103.102	104,456	108.49	112.767	114.322	107.711	78.796	45.444
51. Low-pressure cylinder, head end	96.057	96.599	100.155	100.65	106.708	106.805	101.162	72.362	a9.023
52. Low-pressure cylinder, total	199.130	199.761	204.611	209.14	219.475	221.127	208.874	151.158	94.467
53. Total for the entire engine	494.390	486.492	500.042	509.708	537.224	532.214	509.830	376.365	228.564
Economic Results:									
54. Number of pounds of steam per indicated horse-power per hour	12.822	12.668	12.763	12.789	12.703	12.651	12.735	13.326	15.897
55. Heat units supplied to the engine per indicated horse-power per hour	13,852.500	13,685.	13,780.20	13,809.	13,720.60	13,676.50	13,758.30	14,207.50	14,956.10
56. Equivalent foot-pounds supplied to the engine per indicated horse-power per hour	10,777,245.	10,646,930.	10,720,995.60	10,743,402.	10,674,626.80	10,640,317.09	10,703,957.40	11,123,455.	11,635,845.80
57. Efficiency of engine, actual, per cent	18.554	18.640	18.468	18.430	18.548	18.608	18.498	17.800	17.016
58. Ideal efficiency by second law of thermodynamics	28.755	28.868	28.744	28.484	28.515	28.462	28.631	28.449	28.543
59. Ratio of actual to ideal efficiency	.6452	.6457	.6427	.6470	.6500	.6537	.6468	.6256	.5961

jacket and reheater drip, delivered by the engine to the boiler under normal conditions.

In the tests the drip from the separator was discharged into one weighing tank, and that from the jackets and reheaters into another. The separator drip has been considered simply as moisture in the steam.

The temperature of the water discharged from the jackets and reheaters at the drip tank was found by a short run under normal conditions to agree very closely with the temperature corresponding to the pressure in the low-pressure jacket. The temperature used in the computations has, therefore, been taken as that corresponding to the pressure in the low-pressure jacket, line 20. It was not practicable to determine the heat lost in the Albany trap. This at most is relatively a small quantity, and no attempt has been made to include it in the computations.

The quantity of steam to be credited to the engine, line 7, due to the saving of heat by the feed-water heater and by returning the jacket and reheater drip to the boiler, has been calculated in the following manner: Let W equal the total weight of steam delivered to the engine; w, the weight used in the jackets and reheaters; T, the temperature of the feed water on leaving the heater; t, the temperature of the water discharged by the jackets and reheaters, and x, the temperature of the mixture. Then $(W-w)(x-T) = w(t-x)$, from which $x = T + \frac{w}{W}(t-T)$. Let H equal the total heat required to make one pound of steam at boiler pressure, with feed water at 100 degrees Fahr., as stipulated in the contract; and H', the total heat required at the temperature x; then the saving due to the hotter feed water would be $H-H'$ heat units per pound, and the percentage of saving, $\frac{H-H'}{H}$. It will be sufficiently exact to take $H-H' = x-100$, or equal to the temperature of the feed water above 100 degees Fahr. For example, the average pressures and temperatures for the six days at full speed were as follows:

Pressure in boiler, absolute, pounds per square inch	139.19
Pressure in low-pressure jacket, absolute, pounds per square inch	56.19
Temperature in low-pressure jacket, degrees Fahr., t	288.26
Temperature of feed water at heater, degrees Fahr., T	117.77

Total steam delivered to engine per hour, pounds, W..... 6,493.67
Steam delivered to jackets and reheaters, per hour, pounds, w..... 893.28
Total heat at 139.19 pounds pressure from feed water at 100 degrees Fahrenheit, H..... 1,121.42

The average temperature of the mixture will be,

$$x = 117.77 + \frac{893.28}{6493.67}\ (288.26 - 117.77)$$
$$= 117.77 + 23.453 = 141.223.$$

The fraction $\frac{893.28}{6493.67}$, equal to 0.13756, is the percentage of steam used in the jackets and reheaters, line 10. The method for finding the equivalent temperature of the feed water may then be stated as follows: Multiply the difference between the temperature of the water discharged by the low-pressure jacket and the temperature of the feed water at the heater by the percentage of steam used in the jackets and reheaters, and add the result to the temperature of the feed water at the heater. The temperatures of the feed water thus found are shown in line 33.

The percentage of saving in this case will be,

$$\frac{x - 100}{H} = \frac{41.223}{1121.42} = 0.03676,$$

and the saving in pounds per hour will be 0.03676 × 6493.67 = 238.7, which is to be deducted from 6493.67, leaving 6254.97 as the number of pounds of steam per hour to be charged to the engine. In other words, the engine with the hotter feed uses 3.676 per cent. less fuel than it would if it delivered the feed water to the boiler at 100 degrees Fahr., as specified in the contract. This is equivalent to the amount of fuel required to make 238.7 pounds of steam per hour, or 5,728.8 pounds per day of 24 hours. The use in this computation of the difference of temperatures in place of the difference of the heats of the liquid results is no appreciable error. The credit of allowance to reduce to contract conditions and the net steam charged to the engine appear in lines 7 and 8, respectively.

The quality of the steam is marked dry in line 11, and no allowance has been made for the slight amount of moisture found on the first three days, as recorded in Table X.

General Data and Results.—Lines 12–43 show the corrected average data observed during the tests. Lines 44–52 show the

indicated horse-power for the separate ends and the total for each cylinder. Line 53 shows the total indicated horse-power for the entire engine. These horse-powers have been calculated from the average mean effective pressures of 10 selected cards for each day, taken at times when the speed and water pressure corresponded most nearly to the average for the day.

The economic results are shown in lines 54–59. The number of pounds of steam per indicated horse-power per hour, line 54, is found by dividing the quantities in line 6 by 24 to reduce to 1 hour, and then by the corresponding horse-power in line 53. The heat units supplied to the engine per indicated horse-power per hour, line 55, are found by multiplying the number of pounds of steam per indicated horse-power per hour, line 54, by the number of heat units in 1 pound of steam at boiler pressure, line 12, above the average temperature of the feed water delivered by the engine to the boiler, line 33. The same quantities may be found by dividing the net steam charged to the engine, line 8, by 24, to reduce to 1 hour, and then by the indicated horse-power, line 53, and multiplying the result by the total heat of 1 pound of steam at boiler pressure above 100 degrees, the contract temperature of the feed water. The equivalent foot-pounds of work supplied to the engine per indicated horse-power, line 56, are the quantities in line 55 multiplied by 778, the mechanical equivalent of heat. Line 57 shows the *actual* efficiency of the engine, or the ratio of the foot-pounds per hour in 1 horse-power, 1,980,000, to the foot-pounds of heat supplied, line 56. Line 58 shows the *ideal* efficiency by the second law of thermodynamics, or the ratio of the difference between the temperatures in the boiler and in the condenser to the absolute temperature in the boiler. Line 59 shows the ratio of the actual to the ideal efficiency, and is found by dividing the quantities in line 57 by those in line 58.

Steam Used by the Jackets and Reheaters.—In comparing the average results at the different speeds, given in the last three columns, the first item to attract attention is the increase in the per cent. of steam used by the jackets and reheaters, line 10. For the full-speed test this is 13.756 per cent., for the $\frac{3}{4}$-speed test, 15.068 per cent, and for the $\frac{1}{2}$-speed test, 17.893 per cent. While these quantities represent the percentages of *steam* used by the jackets and reheaters, they do not represent the percentages of *heat* used. The heat given to each pound of steam

in the boiler is the total heat at boiler pressure, line 12, minus the heat of the liquid at the feed-water temperature, line 33. The heat given up by each pound of steam in the jackets and reheaters is the total heat at boiler pressure minus the heat of the liquid at the temperature of the drip from the low-pressure jacket, line 4, Table XIX. This quantity multiplied by the percentage of steam used by the jackets and reheaters, and divided by the heat given to each pound of steam in the boiler, gives the percentage of *heat* used by the jackets and reheaters. These percentages thus found are 11.86 per cent. for the full-speed test, 12.95 per cent. for the ¾-speed test, and 15.30 per cent. for the ½-speed test.

The loss of heat by radiation from the jackets and reheaters is shown in line 27, Table XIX., to be 2.56 per cent. of the total heat given to the steam in the boiler for the full-speed test, 3.26 per cent. for the ¾-speed test, and 5.17 per cent. for the ½-speed test. Deducting the heat lost by radiation from the total heat used by the jackets and reheaters gives for the percentages of heat actually transmitted to the steam passing through the cylinders, 9.30 per cent. for the full-speed test, 9.69 per cent. for the ¾-speed test, and 10.13 per cent. for the ½-speed test.

It appears then that the increase in the per cent. of steam used by the jackets and reheaters, line 10, in the ¾-speed and ½-speed tests, is due principally to the increased effect of the radiation losses. With a better heat insulation this loss could be reduced and the economy of the engine correspondingly increased.

Reheating Effect in the Receivers.—For convenience of comparison, lines 14, 15, 22, 25, 26, 27, and 28 of the last three columns of Table XIV. have been brought together in Table XV., in order to show the reheating effect in the receivers. In the full-speed test, not only was the moisture in the steam entering the receiver evaporated, but the steam was superheated 8.31 degrees in the first receiver, as shown in line 7, and 14.67 degrees in the second receiver, as shown in line 14. In the ¾-speed test the steam was both dried and superheated 12.49 degrees in the first receiver, and 25.42 degrees in the second receiver; and in the ½-speed test, 19.21 degrees in the first receiver, and 44.05 degrees in the second receiver. The differences shown in lines 4 and 11 between the temperatures corresponding to the pressures, lines 2 and 9, and the observed temperatures of the enter-

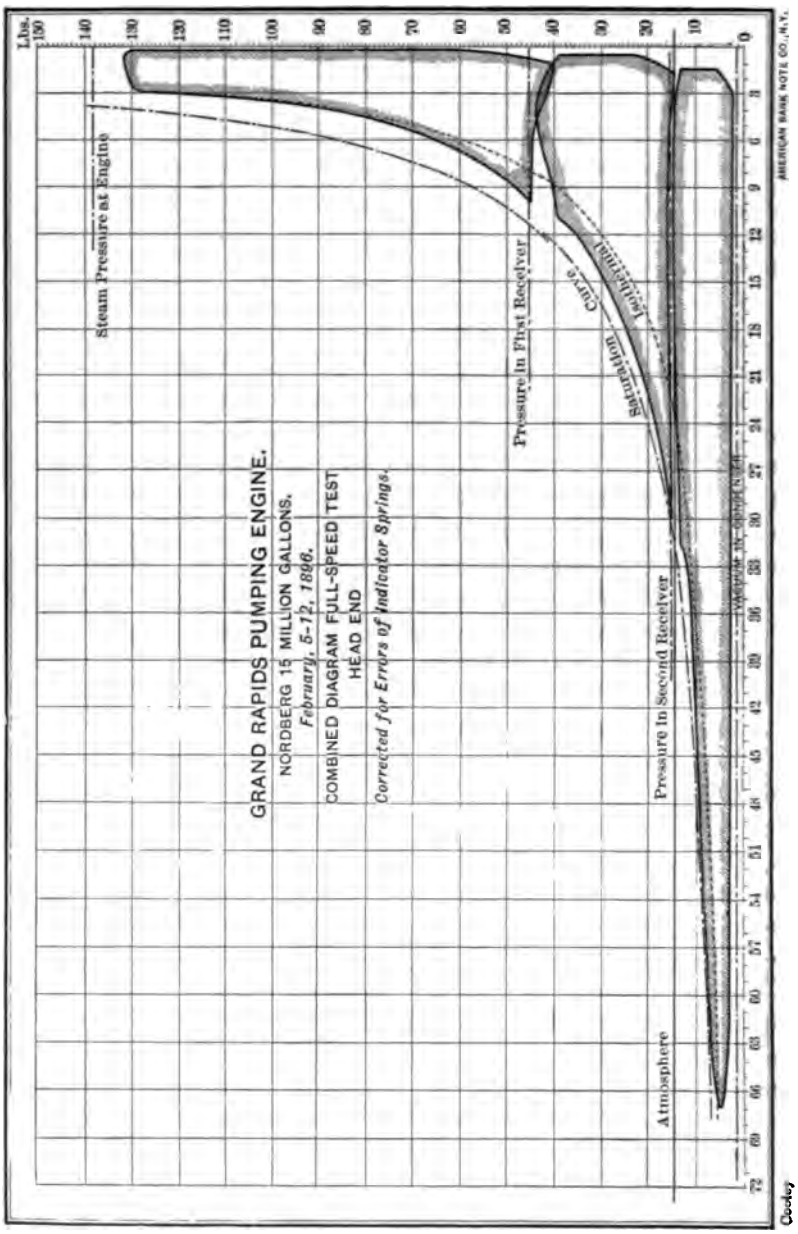

GRAND RAPIDS PUMPING ENGINE.
NORDBERG 15 MILLION GALLONS.
February, 5-12, 1896.
COMBINED DIAGRAM FULL-SPEED TEST
HEAD END
Corrected for Errors of Indicator Springs.
Steam Pressure at Engine
Pressure in First Receiver
Saturation Temperature Curve
Pressure in Second Receiver
Atmosphere
Lbs.
Cooley
AMERICAN BANK NOTE CO., N.Y.

Fig. 351.

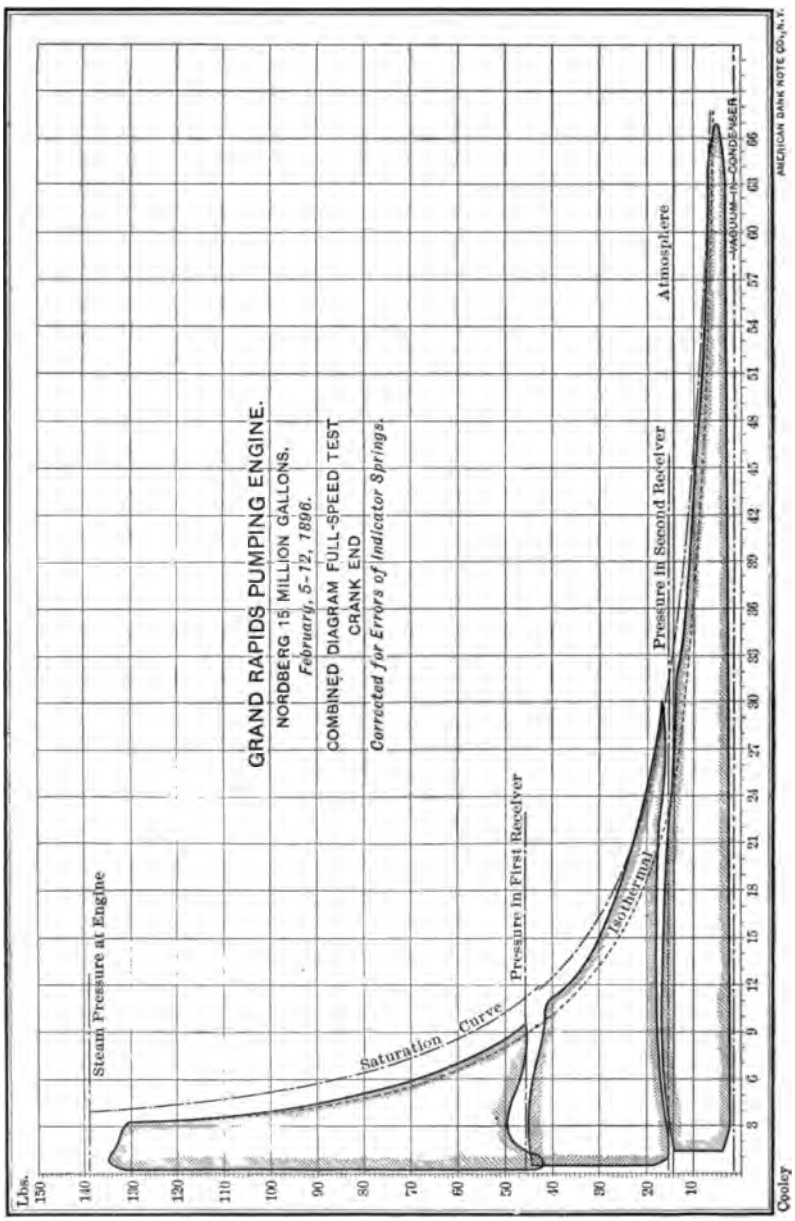

GRAND RAPIDS PUMPING ENGINE.
NORDBERG 15 MILLION GALLONS.
February, 5-12, 1896.
COMBINED DIAGRAM FULL-SPEED TEST
CRANK END
Corrected for Errors of Indicator Springs.
Lbs.
Steam Pressure at Engine
Saturation Curve
Pressure In First Receiver
Isothermal
Pressure In Second Receiver
Atmosphere
VACUUM—IN CONDENSER
Cooley
AMERICAN BANK NOTE CO., N.Y.

FIG. 852.

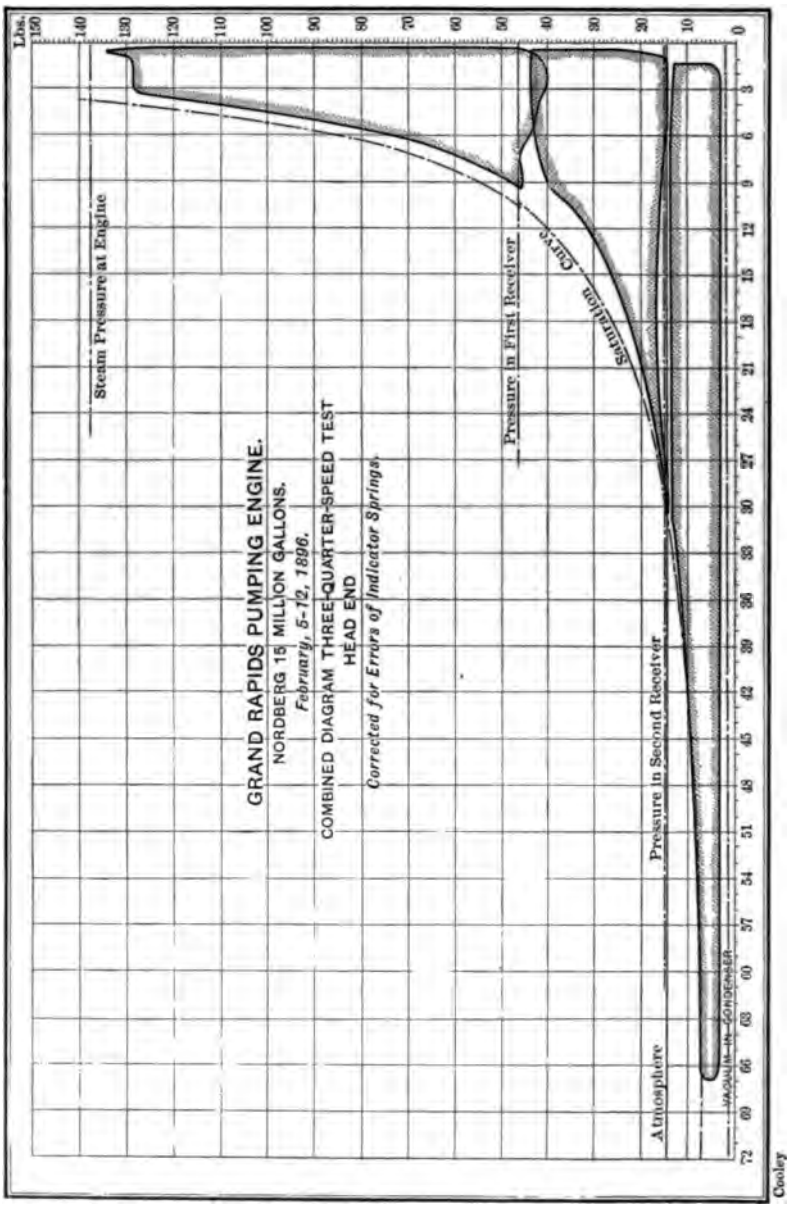

GRAND RAPIDS PUMPING ENGINE.
NORDBERG 15 MILLION GALLONS.
February, 5-12, 1896.
COMBINED DIAGRAM THREE-QUARTER-SPEED TEST
HEAD END
Corrected for Errors of Indicator Springs.
Steam Pressure at Engine
Pressure in First Receiver
Condensation Curve
Pressure in Second Receiver
Atmosphere
VACUUM IN CONDENSER
Lbs.
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51
54
57
60
63
66
69
72
Cooley

FIG. 368.

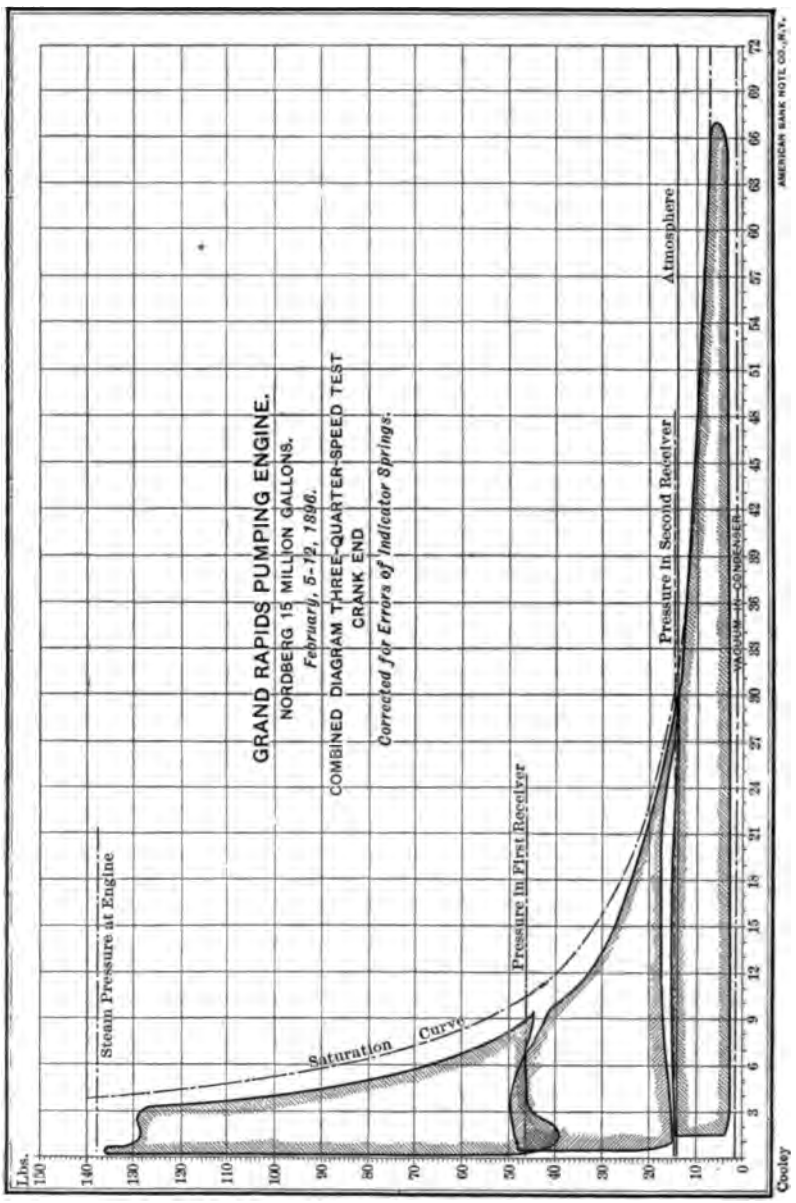

GRAND RAPIDS PUMPING ENGINE.
NORDBERG 15 MILLION GALLONS.
February, 5-12, 1896.
COMBINED DIAGRAM THREE-QUARTER-SPEED TEST
CRANK END
Corrected for Errors of Indicator Springs.
Lbs.
Steam Pressure at Engine
Saturation Curve
Pressure In First Receiver
Pressure In Second Receiver
Atmosphere
VACUUM IN CONDENSER
Cooley
AMERICAN BANK NOTE CO., N.Y.

Fig. 354.

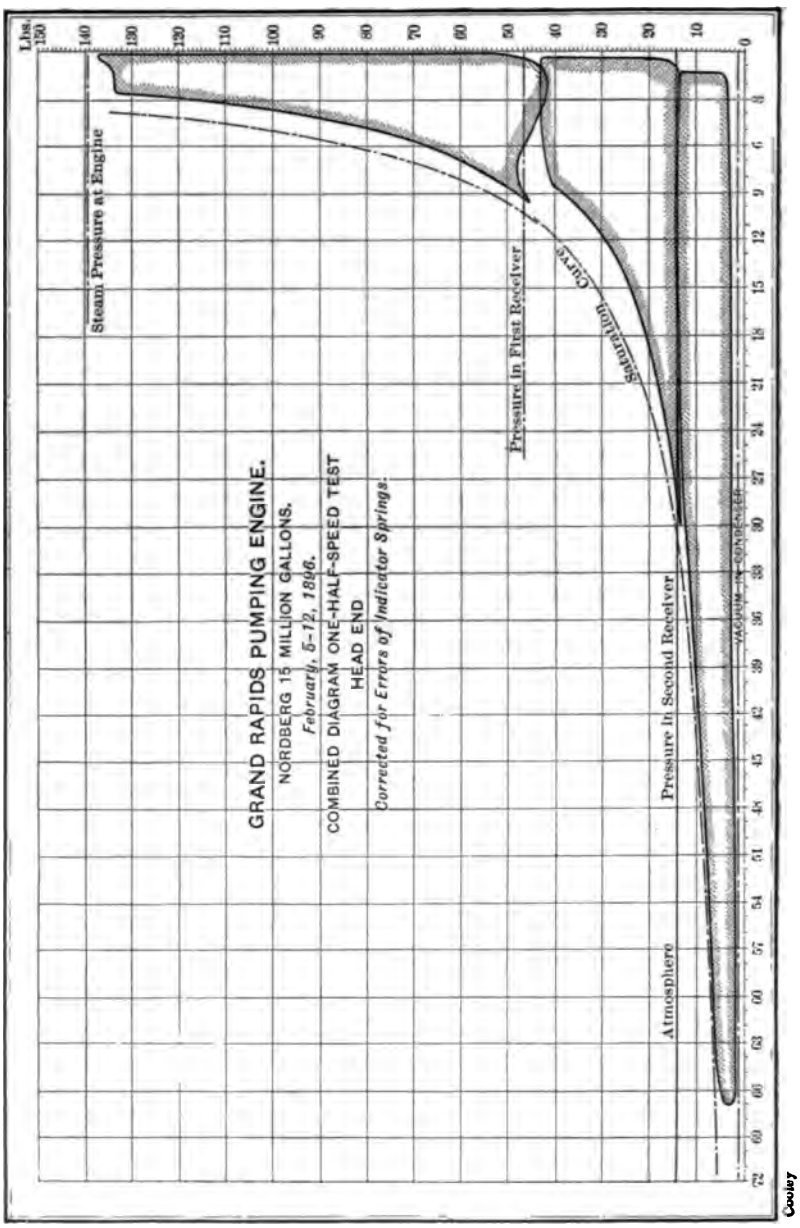

GRAND RAPIDS PUMPING ENGINE.
NORDBERG 15 MILLION GALLONS.
February, 5-12, 1896.
COMBINED DIAGRAM ONE-HALF-SPEED TEST
HEAD END
Corrected for Errors of Indicator Springs.
Steam Pressure at Engine
Pressure in First Receiver
Cut-off
Saturation
Pressure in Second Receiver
Atmosphere
VACUUM IN CONDENSER
Lbs.
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

FIG. 355.

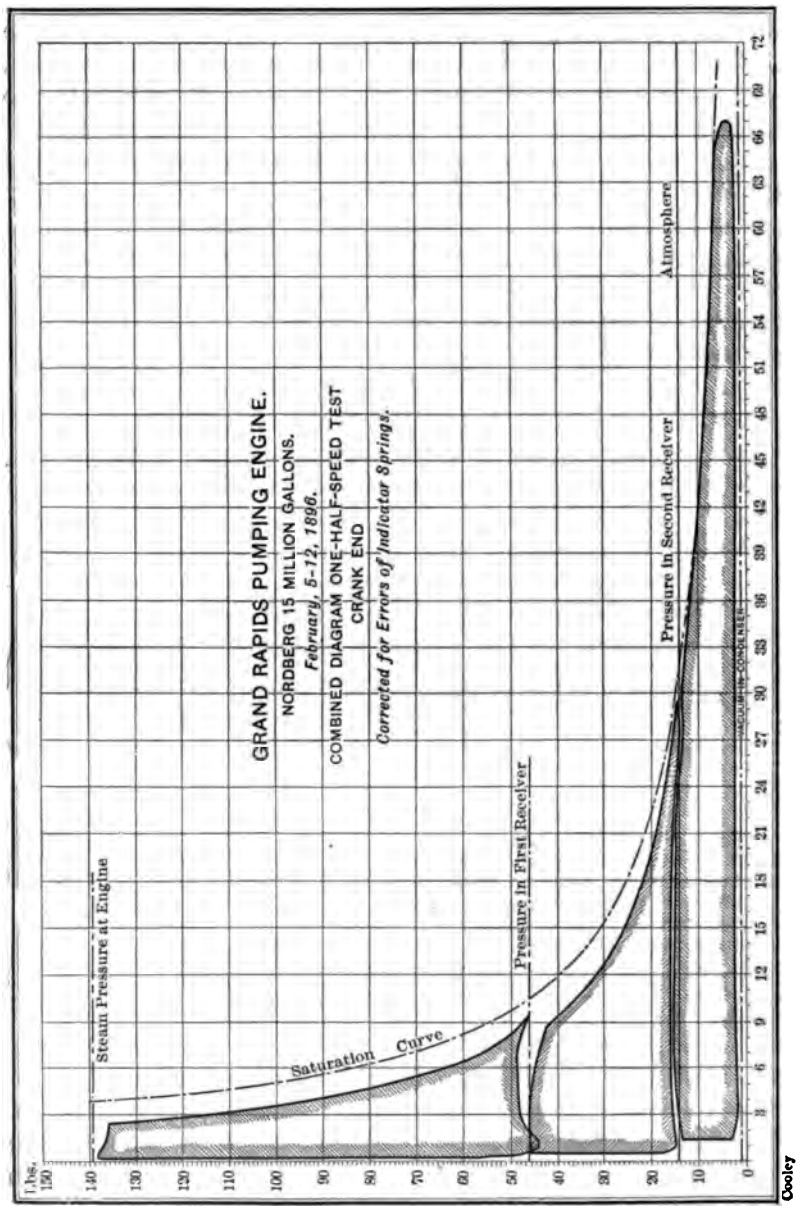

GRAND RAPIDS PUMPING ENGINE.
NORDBERG 15 MILLION GALLONS.
February, 5-12, 1896.
COMBINED DIAGRAM ONE-HALF-SPEED TEST
CRANK END
Corrected for Errors of Indicator Springs.
Steam Pressure at Engine
Saturation Curve
Pressure in First Receiver
Pressure in Second Receiver
Atmosphere
Lbs.
Cooley

FIG. 856.

ing steam, lines 3 and 10, would appear to indicate that the steam on entering the receivers is slightly superheated. The combined diagrams, Figs. 351 to 356, and lines 34 and 36 of Table XVIII., giving the steam accounted for by the indicator, show, however, that this cannot be true. It is more reasonable to assign the difference to the difficulty of obtaining an average reading of the receiver gauges, the indications of which varied a number of pounds during each stroke of the engine.

It is interesting to note the increased superheat at reduced speeds, as shown in lines 7 and 14. This undoubtedly contributed largely to the relatively high economy obtained in the ¾-speed and ½-speed tests.

TABLE XV.

REHEATING EFFECT IN RECEIVERS.

Pressures, average, pounds per square inch; Temperatures, average, degrees Fahr.

	Full-speed Test.	¾-speed Test.	½-speed Test.
First Receiver.			
1. Absolute pressure	45.57	46.41	46.60
2. Temperature corresponding to line 1	275.06	276.20	276.45
3. Temperature of steam entering	276.04	276.60	277.82
4. Difference of lines 2 and 3	0.98	0.40	1.37
5. Temperature of steam leaving	284.85	289.09	297.03
6. Superheat, difference of lines 2 and 5	9.79	12.89	20.58
7. Superheat, difference of lines 3 and 5	8.81	12.49	19.21
Second Receiver.			
8. Absolute pressure	15.31	15.07	14.82
9. Temperature corresponding to line 8	214.05	213.26	212.41
10. Temperature of steam entering	217.93	216.02	215.29
11. Difference of lines 9 and 10	3.88	2.76	2.88
12. Temperature of steam leaving	232.60	241.44	259.34
13. Superheat, difference of lines 9 and 12	18.55	28.18	46.93
14. Superheat, difference of lines 10 and 12	14.67	25.42	44.05

Vacuum in the Condenser.—The vacuum, line 23, is somewhat better at the reduced speeds, as was to be expected. This improvement is in part due to the higher barometer, line 21. The vacuum throughout all the tests might reasonably have been expected to be at least one inch better than shown, in view of the low temperature of the injection water and of the discharge. This would have increased the average from 25.72 inches to 26.72 for the six days of the full-speed test, which

would have been equivalent to about half a pound in the low-pressure cylinder. The average mean effective pressure for the six days, reduced to the low-pressure cylinder, was 22.337 pounds, and an increase of half a pound is equivalent to 2.24 per cent. of this quantity. In other words the engine could have done with the same amount of steam 2.24 per cent. more work with the 1 inch better vacuum.

Economic Results.—Lines 53 and 54 show that the steam consumption per indicated horse-power per hour was 12.735 pounds at 509.83 horse-powers; 13.326 pounds at 376.36 horse-powers, and 13.897 pounds at 228.56 horse-powers. These results are noteworthy and of great practical importance, since they indicate that the engine can be operated at widely varying capacities without much reduction in economy. The desirability of this feature is emphasized by the fact that the water consumption varies at the different seasons of the year, and increases from year to year. This makes it possible to purchase a pumping engine large enough to meet the demands of the future without necessarily sacrificing economy, while the engine is operated at a reduced capacity to meet the demands of the present.

Line 57 shows that the engine utilized 18.50 per cent. of all the heat of the steam delivered to it by the boiler for the full speed test, 17.80 per cent. for the $\frac{3}{4}$-speed test, and 17.02 per cent. for the $\frac{1}{2}$-speed test. These results are shown in line 59 to be 64.68 per cent., 62.56 per cent., and 59.61 per cent., respectively, of the greatest efficiency theoretically possible with the given boiler pressures and the vacuums in the condenser.

The calorific value of the coal used was not determined, and it is impossible, therefore, to state the actual efficiency of the boiler during the tests. Assuming, however, an efficiency of 75 per cent., which is not uncommon, the combined efficiency of the boiler and engine would be 13.87 per cent. for the full-speed test, 13.35 per cent. for the $\frac{3}{4}$-speed test, and 12.76 per cent. for the $\frac{1}{2}$-speed test.

Line 28, Table XIII., shows that 7.126 pounds of water were evaporated per pound of coal under actual conditions, the temperature of the feed water being 116.69 degrees, as shown in line 30, Table XIV. Reducing to the average temperature of the feed water delivered by the engine to the boiler under normal conditions, 141.25 degrees, as shown in line 33, increases the evaporation to 7.289 pounds of water per pound of coal.

The steam consumption per indicated horse-power, line 54, divided by 7.289 gives an actual coal consumption of 1.747 pounds for the full-speed test, 1 828 pounds for the ¾-speed test, and 1.906 pounds for the ½-speed test. Assuming an evaporation of 10 pounds of water per pound of coal under normal conditions, the coal consumption per indicated horse-power would be 1.273 pounds for the full-speed test, 1.333 pounds for the ¾-speed test, and 1.390 for the ½-speed test.

Pressures in the Steam Cylinders.—The pressures of the steam at different points in its course through the engine are shown in Table XVI. These are the average values obtained from ten representative cards taken on the third day of the full-speed test. Lines 28–34 show the drop of pressure in the steam pipe between the boiler and engine to be 0.62 pounds; between the steam pipe and the high-pressure cylinder, 3.79 pounds; between the high-pressure and intermediate cylinders, 0.48 pounds; between the intermediate and low-pressure cylinders, 1.29 pounds; between the low-pressure cylinder and condenser, 0.69 pounds; and between the condenser and air pumps, 0.59 pounds.

Lines 35–46 show the mean effective pressures in the different cylinders and the equivalent mean effective pressures reduced to the low-pressure cylinder.

TABLE XVI.

PRESSURES IN STEAM CYLINDERS, THIRD DAY.

Absolute, pounds per square inch.

1. Average steam pressure at boiler	139.26
2. Average steam pressure at engine	138.64
High-pressure Cylinder:	
3. Maximum admission pressure, crank end	135.06
4. Maximum admission pressure, head end	136.58
5. Maximum admission pressure, average of both ends	135.82
6. Average admission pressure, crank end	134.20
7. Average admission pressure, head end	135.50
8. Average admission pressure, both ends	134.85
9. Average exhaust pressure, crank end	44.63
10. Average exhaust pressure, head end	42.98
11. Average exhaust pressure, both ends	43.81
Intermediate-pressure Cylinder:	
12. Average admission pressure, crank end	45.05
13. Average admission pressure, head end	41.60

14. Average admission pressure, both ends	43.33
15. Average exhaust pressure, crank end	16.98
16. Average exhaust pressure, head end	15.72
17. Average exhaust pressure, both ends	16.35
Low-pressure Cylinder:	
18. Average admission pressure, crank end	15.40
19. Average admission pressure, head end	14.71
20. Average admission pressure, both ends	15.06
21. Average exhaust pressure, crank end	2.71
22. Average exhaust pressure, head end	2.02
23. Average exhaust pressure, both ends	2.37
24. Average pressure in condenser	1.68
Air Pumps:	
25. Minimum pressure, inboard pump	1.16
26. Minimum pressure, outboard pump	1.02
27. Minimum pressure, average for both pumps	1.09
Drop of Pressure:	
28. Between boiler and pipe at engine	0.62
29. Between pipe at engine and maximum admission pressure	2.82
30. Between pipe at engine and average admission pressure	3.79
31. Between high-pressure exhaust and intermediate admission	0.48
32. Between intermediate exhaust and low-pressure admission	1.29
33. Between low-pressure exhaust and condenser	0.69
34. Between condenser and air pumps	0.59
Mean Effective Pressures:	
35. High pressure, crank end	46.965
36. High pressure, head end	44.914
37. High pressure, average of both ends	45.939
38. High pressure reduced to low-pressure cylinder	6.532
39. Intermediate pressure, crank end	14.129
40. Intermediate pressure, head end	14.633
41. Intermediate pressure, average of both ends	14.381
42. Intermediate pressure reduced to low-pressure cylinder	6.475
43. Low pressure, crank end	8.819
44. Low pressure, head end	9.198
45. Low pressure, average of both ends	9.008
46. Sum of mean effective pressures reduced to low-pressure cylinders	23.015

Indicator Diagrams.—Specimen indicator diagrams selected from those taken during the third day of the full-speed test, and during the $\frac{3}{4}$-speed and $\frac{1}{2}$-speed tests, are shown in Figs. 351 to 356. It will be observed that the admission pressure on the crank end of both the intermediate and the low-pressure cylinders is greater than on the head end; also, that the exhaust pressure on the crank end of the high and intermediate cylinders is greater than on the head end. This is likewise shown

in lines 9, 10, 12, 13, 15, 16, 18, and 19 of Table XVI., the values given being averages obtained from 10 cards, taken during the third day of the full-speed test.

The different steam cylinders of the engine are so connected that the crank end of the intermediate-pressure cylinder takes the greater part of its steam from the crank end of the high, and the crank end of the low-pressure cylinder takes the greater part of its steam from the crank end of the intermediate. It might seem at first thought that the difference between the cards from the crank end and from the head end was caused by unequal cut-offs in the high-pressure cylinder. This was not the case, however, as a change in the cut-off produced no material improvement.

A careful study of the working of the engine shows that the unequal admission pressures are due to the effect of the angularity of the connecting rod upon the motion of the pistons. For instance, the sequence of cranks being high, low, and intermediate, when the intermediate piston is at the beginning of its *forward* stroke, the high-pressure piston has not quite reached $\frac{1}{4}$ of its return stroke. When the intermediate piston is at the beginning of its *return* stroke, the high-pressure piston is just beyond $\frac{1}{4}$ of its forward stroke. Except for the angularity of the connecting rod, the high-pressure piston would be at exactly $\frac{1}{4}$ of its stroke in both cases. In passing from the first position to the second, the high-pressure piston completes a little *more* than $\frac{3}{4}$ of its return stroke, and also passes through a little *more* than $\frac{1}{4}$ of its forward stroke. In passing from the second position to the first the high-pressure piston completes a little *less* than $\frac{3}{4}$ of its forward stroke, and passes through a little *less* than $\frac{1}{4}$ of its return stroke. It follows, therefore, that while the intermediate piston makes its forward stroke, the high-pressure piston discharges more steam than while the intermediate piston makes its return stroke. In a similar manner, it can be shown that while the intermediate piston passes from the point of cut-off on its forward stroke to the point of cut-off on its return stroke, the high-pressure cylinder discharges more steam into the first receiver than it discharges while the intermediate piston is returning to its first position. The effect of this is to raise the admission pressure during the return, or crank end, stroke, and to diminish it during the forward, or head end, stroke. The unequal admission pressures in the low-pressure cylinder

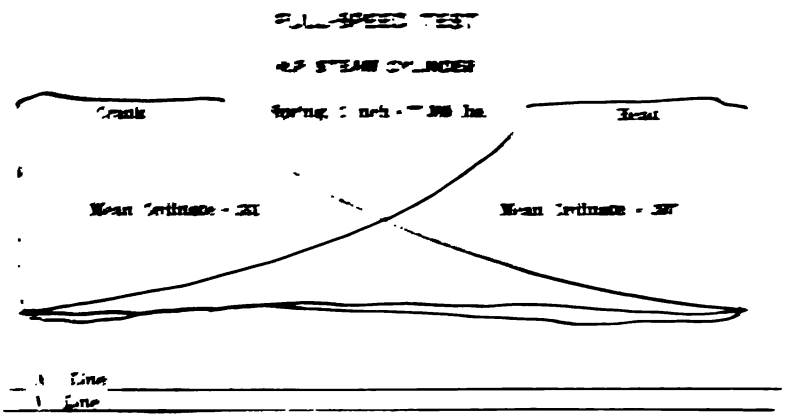
are similarly explained. The quantitative results obtained by a graphical analysis of this action are shown in Table XVII.

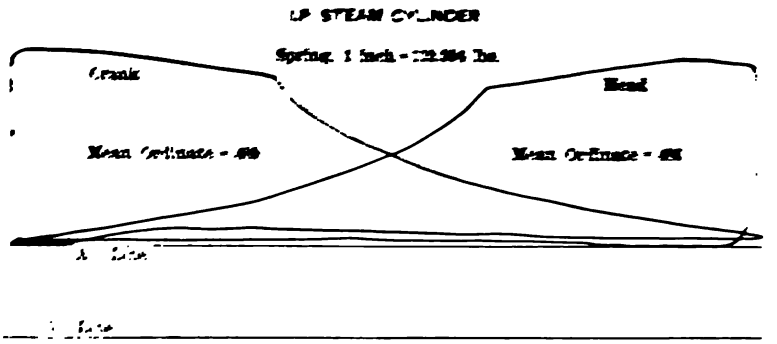
TABLE XVII.

DISTRIBUTION OF STEAM AS AFFECTED BY ANGULARITY OF CONNECTING ROD.

Point of Cut-off.	
1. High pressure, crank end	0.302
2. High pressure, head end	0.314
3. Intermediate pressure, crank end	0.362
4. Intermediate pressure, head end	0.358
5. Low pressure, crank end	0.455
6. Low pressure, head end	0.459
7. Ratio of connecting rod to crank	5.0
Volume of Steam Discharged from High-Pressure Cylinder into First Receiver, Cubic Feet.	
8. Between cut-off on intermediate forward stroke, and beginning of return stroke	4.7
9. Between cut-off on intermediate return stroke, and beginning of forward stroke	2.8
10. Between cut-off on intermediate forward stroke, and cut-off on return stroke	10.4
11. Between cut-off on intermediate return stroke, and cut-off on forward stroke	8.2
Volume of Steam Discharged from Intermediate Cylinder into Second Receiver, Cubic Feet.	
12. Between cut-off on low-pressure forward stroke, and beginning of return stroke	12.9
13. Between cut-off on low-pressure return stroke, and beginning of forward stroke	7.9
14. Between cut-off on low-pressure forward stroke, and cut-off on return stroke	32.2
15. Between cut-off on low-pressure return stroke, and cut-off on forward stroke	26.9

Combined Diagrams.—The indicator diagrams for each cylinder shown on Figs. 357, 358, and 359, have been combined on Figs. 351 to 356, so as to show the action of the steam continuously from the time it is admitted to the high-pressure cylinder until it is exhausted from the low-pressure cylinder. The combined diagrams of the head end and crank end for the third day of the full-speed test are shown on Figs. 351 and 352, respectively; those for the $\frac{3}{4}$-speed test are shown on Figs. 353 and 354, and those for the $\frac{1}{2}$-speed test, on Figs. 355 and 356. The vertical scale represents pressures in pounds per square inch absolute, corrected for errors of indicator springs, and the horizontal


[illegible]-SPEED TEST
[illegible] STEAM CYLINDER
Crank
Spring: 1 inch = [illegible] lbs.
Head
Mean Ordinate = [illegible]
Mean Ordinate = [illegible]
Line
Line


LP STEAM CYLINDER
Spring: 1 inch = [illegible] lbs.
Crank
Head
Mean Ordinate = [illegible]
Mean Ordinate = [illegible]
Line
Line

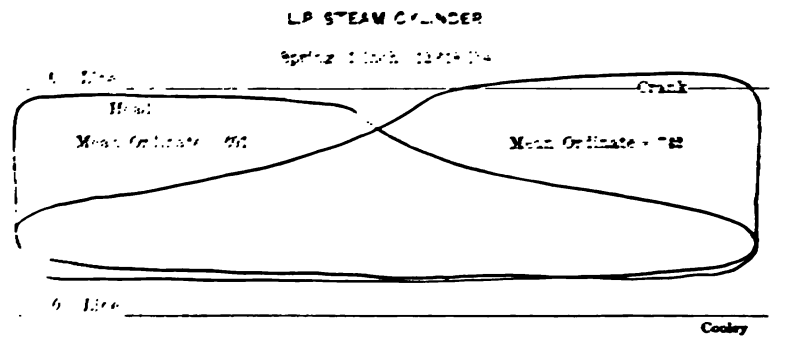
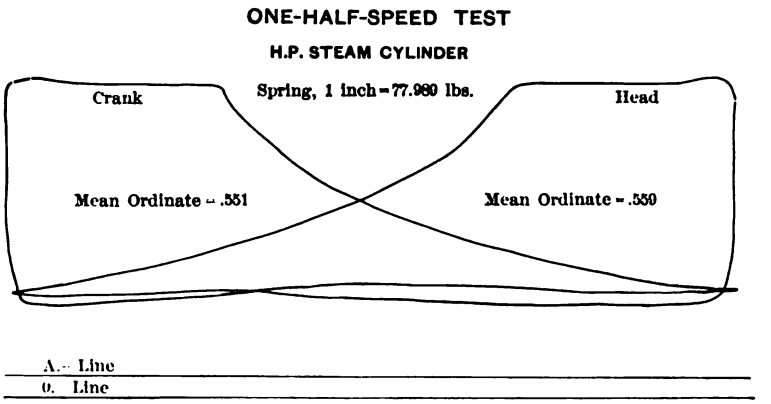

LP STEAM CYLINDER
Spring: 1 inch = [illegible] lbs.
Line
Crank
Head
Mean Ordinate = [illegible]
Mean Ordinate = [illegible]
Line
Cooley

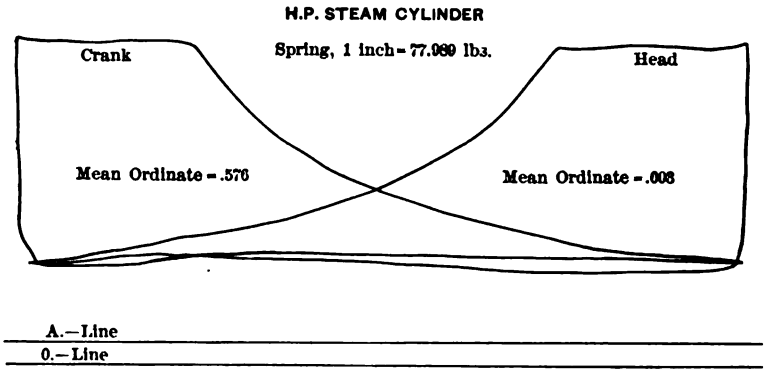
FIG. 357.

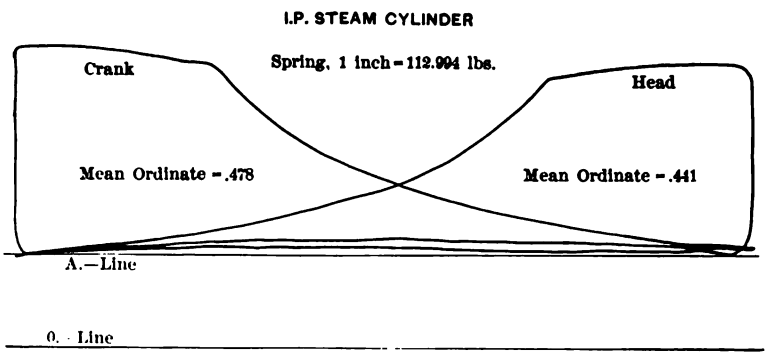


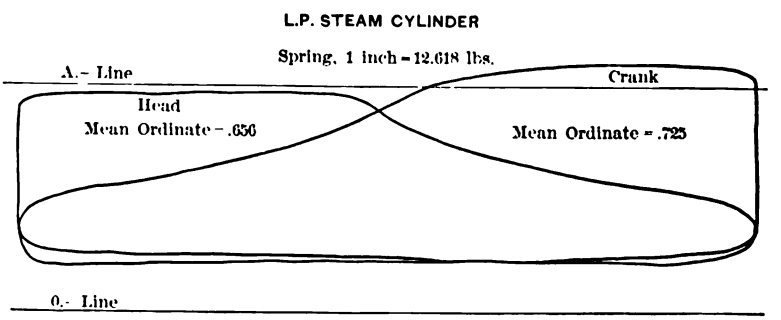
Cooley

68 FIG. 858.

THREE-QUARTER-SPEED TEST







Cooley

FIG. 359.

scale, volumes in cubic feet. The diagrams also show the pressure of the steam before admission to the engine, the pressures in the first and second receivers, and the vacuum in the condenser, which were observed at the time the cards were taken. Simultaneous cards could not be obtained; an interval, usually of about three minutes, was required to complete the set.

The lack of correspondence between the exhaust and the admission lines is due to the method of combining the diagrams, to the relative positions and velocities of the pistons, and to the reheating effect of the receivers. Some of the greater variations, as, for instance, that shown between the high pressure and intermediate diagrams (Figs. 352, 355), may be due not only to the causes mentioned, but also to the fact that the cards were not taken simultaneously.

The saturation curve, which is shown on each of the diagrams, was plotted on the assumption that the steam was equally divided between the two ends of the cylinders. This is not strictly correct, as appears from lines 10, 11, 14, and 15 of Table XVII. The slight breaks in the curve, where it passes from one cylinder to the next, are due to the difference in the weights of steam in the clearance spaces.

The saturation curve represents the expansion curve of steam free from moisture. A comparison of this curve with the actual curve shows at once the condition of the steam at all points. The horizontal distance from the vertical base line to the actual curve, divided by the horizontal distance to the saturation curve, gives the quality of the steam. The diagram shows that when the steam begins to expand in each of the cylinders, it contains a certain amount of moisture, due to condensation of the steam in contact with the cooler cylinder walls. In the earlier part of the expansion the separation of the curves shows an increase of moisture; as the expansion continues, the approach of the curves shows a decrease of moisture, due to reëvaporation. By the time the steam has reached the end of its expansion in the second cylinder, the moisture has nearly or quite disappeared, the curves being close together. In the third cylinder the actual curve touches, and in some cases crosses, the saturation curve, showing not only that the moisture has disappeared, but, in the latter case, that the steam is superheated.

The use of several cylinders, as in a multiple-expansion en-

gine, reduces the initial condensation losses, and admits of a more complete reëvaporation than is possible with one or two cylinders. The addition of reheating receivers still further reduces these losses, especially when the steam is superheated by them. The high economy realized on the $\frac{3}{4}$-speed and $\frac{1}{2}$-speed tests is, without doubt, largely due to the superheating effect of the reheating receivers. as shown in lines 7 and 14 of Table XV.

Steam Accounted for by the Indicator.—The steam accounted for by the indicator at cut-off and at release in each of the cylinders has been calculated in the usual manner. For the cut-off used in the calculations, a point was selected on the expansion curve as near as possible to the actual cut-off on all of the cards. For the high-pressure cylinder, the point selected was at 0.33 stroke for the full-speed and $\frac{3}{4}$-speed tests, and at 0.27 stroke for the $\frac{1}{2}$-speed test. For the intermediate cylinder, the point selected was at 0.38 stroke for the full-speed test, and at 0.33 stroke for the $\frac{3}{4}$-speed and $\frac{1}{2}$-speed tests. For the low-pressure cylinder the point selected was at 0.5 stroke for all the tests. For the release, a point was selected on the expansion curve at 0.9 stroke, as near as possible to the actual release on the low-pressure cards. The same point was chosen on the high pressure and intermediate cards for purposes of comparison.

The results obtained are given in Table XVIII. Lines 1–9 show the actual points of cut-off as measured from the cards. Lines 10–12 show the ratio of expansion in the different cylinders. The total ratio of expansion, line 13, was 22.11 for the full-speed test, 23.93 for the $\frac{3}{4}$-speed test, and 27.16 for the $\frac{1}{2}$-speed test. Lines 14–31 show the number of pounds of steam accounted for per stroke by the indicator, and line 32 the steam per revolution as weighed to the engine. Lines 33–39 show the quality of the steam. The quality on entering the high-pressure cylinder being 100.00, or dry, it was for the full-speed test 72.04 at high-pressure cut-off, 84.66 at high-pressure release, 85.49 at intermediate cut-off, 96.98 at intermediate release, 91.57 at low-pressure cut-off, and 99.64 at low-pressure release. For the $\frac{3}{4}$-speed test the quality at high-pressure cut-off was 67.76, and at low-pressure release it was superheated 15.47 degrees. For the $\frac{1}{2}$-speed test the quality at high-pressure cut-off was 61.69, and at low-pressure release it was superheated 17.41 degrees.

TABLE XVIII.

STEAM ACCOUNTED FOR BY THE INDICATOR.

	Full-speed Test. 3d Day.	¾-speed Test.	½-speed Test.
Fraction of Stroke Completed at Actual Cut-off.			
1. High pressure, crank end	0.302	0.274	0.244
2. High pressure, head end	0.314	0.294	0.251
3. High pressure, average for both ends	0.308	0.284	0.247
4. Intermediate, crank end	0.362	0.308	0.287
5. Intermediate, head end	0.358	0.304	0.287
6. Intermediate, average for both ends	0.360	0.306	0.287
7. Low pressure, crank end	0.455	0.462	0.452
8. Low pressure, head end	0.459	0.469	0.454
9. Low pressure, average for both ends	0.457	0.465	0.458
Ratio of Expansion.			
10. In high-pressure cylinder, average for both ends	3.125	3.388	3.885
11. In intermediate cylinder, average for both ends	2.699	3.145	3.341
12. In low-pressure cylinder, average for both ends	2.135	2.100	2.153
13. Total for the three cylinders	22.112	23.928	27.162
Pounds of Steam per Stroke, Average of 10 *Cards.*			
14. High pressure at cut-off, crank end	0.828	0.780	0.694
15. High pressure at cut-off, head end	0.834	0.819	0.714
16. High pressure at cut-off, total for both ends	1.662	1.599	1.408
17. High pressure at 0.9 stroke, crank end	0.985	0.976	0.940
18. High pressure at 0.9 stroke, head end	0.969	1.000	0.934
19. High pressure at 0.9 stroke, total for both ends	1.954	1.976	1.874
20. Intermediate at cut-off, crank end	1.009	0.939	0.872
21. Intermediate at cut-off, head end	0.964	0.876	0.839
22. Intermediate at cut-off, total for both ends	1.973	1.814	1.711
23. Intermediate at 0.9 stroke, crank end	1.159	1.127	1.067
24. Intermediate at 0.9 stroke, head end	1.079	1.092	0.976
25. Intermediate at 0.9 stroke, total for both ends	2.238	2.220	2.043
26. Low pressure at cut-off, crank end	1.084	1.135	1.099
27. Low pressure at cut-off, head end	1.030	1.059	1.034
28. Low pressure at cut-off, total for both ends	2.113	2.194	2.133
29. Low pressure at 0.9 stroke, crank end	1.182	1.241	1.220
30. Low pressure at 0.9 stroke, head end	1.118	1.176	1.124
31. Low pressure at 0.9 stroke, total for both ends	2.299	2.417	2.344
32. Steam per revolution entering cylinder, as weighed	2.308	2.368	2.282
Percentage of Steam Accounted For.			
33. High pressure at cut-off	72.04	67.76	61.69
34. High pressure at 0.9 stroke	84.66	83.73	82.14
35. Intermediate at cut-off	85.49	76.87	74.99
36. Intermediate at 0.9 stroke	96.98	94.04	89.53
37. Low pressure at cut-off	91.57	92.97	93.48
38. Low pressure at 0.9 stroke	99.64	100.00	100.00
39. Degrees of superheat at 0.9 stroke	.....	15.47	17.41

Disposition of Heat.—By reason of the unusually complete data which were obtained, it is possible to determine with con-

siderable accuracy the disposition of the heat energy which is delivered to the engine. Of the heat which comes to the engine with each pound of steam one portion is converted into useful mechanical work; another portion is lost by radiation and convection to surrounding objects; a third portion is carried away with the water of condensation from the jackets and reheaters, and a fourth portion passes out with the exhaust steam to the feed-water heater and to the condenser.

In the computations and the accompanying table all quantities of heat have been measured as above 32 degrees Fahr.

The heat received per pound of steam is the total heat of steam at boiler pressure, the steam being found to be dry saturated steam.

The heat converted into work is found by dividing 1,980,000, the number of foot-pounds per hour in 1 horse-power, by the number of pounds of steam per hour per indicated horse-power, and by 778, the mechanical equivalent of heat.

The heat lost by radiation and convection was determined by the two radiation tests (Table VI.), and was found to be the heat which is given up by 192.59 pounds of steam per hour in condensing to water at the temperature existing in the low-pressure jacket. The average steam pressure at the boiler during the radiation tests was 124.73 pounds gauge, and the pressure in the low-pressure jacket was found by a subsequent test under the same conditions to be 59.34 pounds gauge. Consequently, the heat lost per hour by radiation and convection was 175,990 heat units Dividing this quantity by the total number of pounds of steam used per hour gives the heat units lost per pound of steam by radiation and convection, as shown in line 16 of Table XIX. It has been assumed that the radiation losses were the same for all the tests—an assumption which is not strictly true, for the reason that during the radiation tests the steam pressure in the jackets and reheaters was greater than when the engine was running. This will help to explain the excess of heat accounted for, as shown in lines 20 and 29 of the table.

The heat carried away with the water of condensation from the jackets and reheaters per pound of steam is the heat of the liquid at the pressure existing in the low-pressure jacket multiplied by the percentage of jacket water.

The heat carried out with the exhaust steam from the low-

pressure cylinder has been obtained in the following manner: From Table XVIII., the quality of the steam at 0.9 of the low-pressure forward stroke is known. Beyond this point the steam does external work equal to the gross work of the last 0.1 of the low-pressure forward stroke; and work is done upon the steam in forcing it out of the cylinder during the return stroke. If no additional heat is received from the cylinder walls, the heat carried away by the steam must be equal to the actual heat in the steam at 0.9 of the low-pressure forward stroke minus the heat equivalent of the gross work done during the remainder of the stroke, plus the heat equivalent of the work done upon the steam during the return stroke. This quantity is found in line 14 of Table XIX.

In line 21 of the table it has been assumed that all of the heat in the jacket water is recovered. As ordinarily connected, the condensation from the jackets and reheaters is returned direct to the boiler by means of an Albany return steam trap. Some heat is undoubtedly lost in the operation of the trap, but, its amount being unknown, no account has been taken of it.

The heat (above 32 degrees) recovered from the exhaust steam by the feed-water heater (line 22) is found by multiplying the heat of the liquid at the temperature of the feed water at the heater by the proportional part of the steam which enters the cylinders.

The excess of heat accounted for is within the limits of error of determining the quality of the steam by the indicator, being less than 1 per cent. of the total quantity of heat involved.

It may at first thought seem impossible to have superheated steam at 0.9 of the low-pressure forward stroke without obtaining superheat in the exhaust also—compare line 7 of Table XIX. and line 29 of Table XIV. That it is possible can be shown in the following manner: In the ½-speed test, where the steam was found to be superheated 17.41 degrees at 0.9 of the low-pressure forward stroke, the actual heat in the steam at that point was 883.13 heat units (line 13 of Table XIX.). Between 0.9 of the low-pressure forward stroke and the end of the return stroke, when the steam had been expelled from the cylinder, the net energy added to the steam was 21.52 heat units (line 12, Table XIX.), making the total energy carried away in the exhaust 904.65 heat units (line 14). In order that

the exhaust steam may leave the low-pressure cylinder under a pressure of 3.2 pounds absolute and in a saturated condition, each pound must receive an amount of heat above 32 degrees equal to the total heat at 3.2 pounds absolute, or 1,125.8 heat units.

Since 82.107 per cent. of the total steam used passed through the cylinders, the heat carried away in the exhaust steam per pound of total steam used would have been $1,125.8 \times 0.82107 = 924.36$ heat units if the steam had been dry and saturated as it left the low-pressure cylinder. The heat which the steam actually carried away was 904.65 heat units, or 19.71 heat units less than would have been required to produce saturation. In other words, although the steam was superheated 17.41 degrees at 0.9 of the low-pressure forward stroke, yet it contained 2.3 per cent. of moisture when it passed out through the exhaust pipe.

In making these calculations, it has been assumed that the heat received by the steam beyond 0.9 of the low-pressure stroke, other than that derived from the mechanical works, was so small that it could be neglected. M. Hirn has shown that the amount of heat received from the cylinder walls during the exhaust stroke and carried direct to the condenser depends upon the per cent. of moisture in the steam at the end of the forward stroke. He quotes two cases where the percentage of moisture at the end of the forward stroke was between 4 and 6, and the amount of heat received during the exhaust stroke was only about 1 per cent. It seems probable, therefore, that in this case, where the steam was dry or superheated at the end of the forward stroke, the heat received during the exhaust stroke was only a fraction of 1 per cent., and may be neglected without introducing material error.

TABLE XIX.

Disposition of Heat.

Heat Units per Pound of Total Steam to Engine.

	Full-speed Test. 3d Day.	¾-speed Test.	½-speed Test.
1. Boiler pressure, absolute, pounds per square inch	139.26	139.41	140.34
2. Per cent. of steam used in jackets and reheaters	13.952	15.068	17.893
3. Steam pressure in low-pressure jacket, absolute, pounds per square inch	56.57	63.79	71.87
4. Heat of the liquid at pressure in low-pressure jacket, heat units	258.1	266.0	274.0
5. Per cent. of steam used in cylinders	86.048	84.932	82.107
6. Per cent. of steam shown by indicator at 0.9 low-pressure forward stroke	90.64		
7. Degrees of superheat shown at 0.9 low-pressure forward stroke		15.47	17.41
8. Average pressure of last 0.1 low-pressure forward stroke, absolute	6.98	6.38	6.23
9. Average pressure of low-pressure exhaust stroke, absolute	2.37	3.10	3.20
10. Heat equivalent of gross work done in last 0.1 low-pressure forward stroke	6.33	5.44	5.50
11. Heat equivalent of work done in low-pressure exhaust stroke	21.57	26.42	27.02
12. Net work expended on steam beyond 0.9 low-pressure forward stroke, heat units	15.24	20.98	21.52
13. Actual heat in steam at 0.9 low-pressure forward stroke	914.91	912.98	883.13
14. Total energy carried away in exhaust steam, heat units	930.15	933.91	904.65
15. Heat carried away in jacket water	36.01	40.08	49.03
16. Heat lost by radiation	27.57	35.07	55.39
17. Heat equivalent of useful work done	199.40	190.98	183.18
18. Total heat accounted for	1,193.14	1,200.04	1,192.20
19. Total heat at boiler pressure	1,189.42	1,189.44	1,189.57
20. Excess of heat accounted for	3.72	10.60	2.63
21. Heat recovered from jacket water	36.01	40.08	49.03
22. Heat recovered from exhaust steam, by heater.	73.85	74.82	69.81
23. Total heat recovered	109.86	114.90	118.84
24. Heat unrecovered in the exhaust	856.3	859.09	834.84
25. Net heat delivered to engine per pound of steam	1,079.56	1,074.54	1,070.73
26. Per cent. of net heat converted into useful work	18.47	17.77	17.10
27. Per cent. of net heat lost by radiation	2.56	3.26	5.17
28. Per cent. of net heat unrecovered in the exhaust	79.32	79.95	77.97
29. Total per cent. accounted for	100.35	100.98	100.24

Pump Tests.

The performance of the pump is of more than ordinary interest, in view of the high plunger speed. Formerly 100 and 150 feet were common speeds; and 200 feet was regarded as excessive. During recent years the tendency has been toward an increase of plunger speed, 300 and 400 feet per minute being commonly used by some builders, while occasionally a speed of 500 or 600 feet per minute is found. The use of these higher plunger speeds has demanded larger valve areas and pump passages, as well as special construction to reduce shocks and to secure smoothness of action. The result has been a reduction in the size of pump for a given capacity, and a corresponding reduction in the cost. At the same time these higher speeds, together with improved methods of working the steam, have resulted in a higher duty, and, consequently, in a greatly reduced coal consumption. Duties of 130,000,000 and 140,000,000 may now reasonably be expected and demanded, where formerly 100,000,000 and 110,000,000 were considered good.

These improvements should be very welcome to the public, as they result not only in a reduced first cost of the pumping machinery, but also in a material saving in the cost of operation.

It will add to the interest and to a fuller appreciation of the results of the pump tests, to include in this report the following extracts from the Instructions to Bidders:

"The engine to have ample capacity to deliver 15,000,000 United States gallons of water in 24 hours, pumping against a total head of 170 feet, from extreme low water in Grand River to high water in water-works reservoir. Two per cent. will be allowed for loss of action due to the probable imperfect filling of the pump. The steam pressure shall not exceed 125 pounds per square inch at the boilers."

"The piston speed must be specified, also the stroke and diameter of the steam pistons and pump plungers."

"The pumps must be of the outside packed plunger type."

"Bidders will state the valve area of the pumps and the amount of clearance in each steam cylinder."

"The area of the suction and discharge valves shall be sufficient to insure proper filling and discharging of the pumps under all conditions, but in no case shall the total suction valve

water-way or the total discharge valve water-way of the engine be less than fourteen (14) square feet."

"The radius of the curves in both suction and discharge pipes to be equal to at least four diameters of the pipe."

"In awarding the contract, economy in operation shall be a primary consideration, and no bid will be considered in which the guarantee duty is less than one hundred and thirty-five (135) million foot-pounds."

"The engine shall be subjected to a capacity and a duty test of 144 consecutive hours' duration, at full capacity."

"The contractor must guarantee that the engine, at full capacity, shall develop a certain number of million foot-pounds based upon each 1,000 pounds of dry steam supplied to the engine, at a steam pressure not exceeding 125 pounds per square inch in the boilers, and a feed-water temperature to be stated in the bid."

"The pressure against which the pumps work will be measured by a gauge attached to the force main past the pump, to which will be added the vertical distance between this gauge and the surface of water in the well."

"No allowance will be made for friction."

"The steam required to supply the boiler-feed pump, the air pump, steam jackets, reheaters, traps, etc., shall not be deducted when above duty is being computed."

"The volume of water pumped shall be determined by plunger displacement."

"In case the engine shall fail to show the guaranteed capacity, or give the guaranteed duty, or comply with the specifications, proposals, and statements, the contractor shall, at the option of the Board of Public Works, remove the same or submit to such forfeiture as may be determined upon at the time of making the award, and which shall be incorporated in the contract."

In compliance with these instructions, the Nordberg Manufacturing Company proposed to furnish "one horizontal triple-expansion condensing pumping engine, of ample capacity to deliver 15,000,000 United States gallons of water per 24 hours, against a total head of 170 feet, as per specifications and plans forming a part of this proposition, and in accordance with instructions to bidders." . . . They further guaranteed "that the engine shall deliver 15,000,000 United States gallons of water per 24

hours, against a total head of 170 feet, with a boiler pressure of not more than 125 pounds to the square inch. Working under this condition . . . to develop a duty of 145,000,000 foot-pounds per 1,000 pounds of dry steam supplied to the engine, including all steam necessary to supply jackets and reheaters, feed pump, and traps. The amount of steam used to be calculated from the amount of feed water supplied to the boiler and evaporated from a temperature of 100 degrees Fahr. The amount of water pumped to be calculated from the plunger displacement, the engine running at a speed of 320 feet per minute, and making 40 revolutions per minute."

Subsequently, the plungers were increased in diameter from 16½ to 17 inches. Assuming 2 per cent. slip, and allowing for the rods, the plunger speed to give the required capacity with the 17-inch plungers would be 308 feet per minute, and the revolutions 38.5.

It was further stipulated in the contract that "in case the engine shall fail to give the guaranteed duty of one hundred and forty-five million foot-pounds," the contractor "agrees to accept a reduction from the contract price for said pumping engine, the amount of such reduction to be based upon the excess of coal required, over and above the amount of coal that the engine would consume had it given the guaranteed duty, this reduction to be based upon the price paid for fuel used by 'the purchaser' at the time of making the test, allowing 6 per cent. for depreciation and repairs. This estimated reduction to be prepared and determined upon by the engineers employed in making the test."

The principal dimensions of the pumps appear in Table III., and the performance in Table XX.

The first six columns of Table XX. contain the results for each day of the full-speed test; the 7th column, the average result for the entire test, and the 8th and 9th columns the results of the tests at reduced speed. The fifth day being Sunday, during which the elevators were not much in use, it was possible to operate the pumps at a higher plunger speed. The pumps were operated against the greatest head during the sixth day.

General Data and Results.—Lines 1 and 2 show the steam used by the engine, line 1 being the same as line 8 of Table XIV. Upon this the duty is based by the terms of the contract.

TABLE XX.

PERFORMANCE OF PUMP.

Test of February 5–12, 1896.

	First Day.	Second Day.	Third Day.	Fourth Day.	Fifth Day.	Sixth Day.	Average, Six Days.	Three-quarter Speed Test.	One-half Speed Test.
Duration of test, hours.....	24	24	24	24	24	24	24	12	12.25
Steam Used:									
1. Total number pounds charged to pumps, net..	152,138.54	147,922.35	153,163.99	156,474.84	163,792.04	161,596.29	155,848.01	60,185.97	38,909.95
2. Number of pounds charged to pumps, per hour.....	6,339.106	6,163.43	6,381.83	6,519.78	6,824.67	6,733.18	6,493.66	5,015.50	3,1 6.29
Water Pressures, Average, pounds per sq. in., Gauge:									
3. In discharge main, gauge on main.....	67.212	65.483	66.723	66.741	68.022	71.823	67.667	67.443	63.842
4. In discharge main, gauge on gauge board	67.08	65.29	66.40	66.52	67.75	71.56	67.433	66.96	63.57
Vacuum, Corrected to Gauge on Pressure Main:									
5. In suction, inches of mercury	.....	13.76	13.927	14.007	14.187				
6. In suction, pounds per square inch.....	... .	6.755	6.834	6.873	. 61				
Suction Head, By Float:									
7. Distance below centre of gauge on discharge main, feet.....	15.247	15.271	15.449	15.576	15.614	16.034	15.532	16.118	17.361
8. Equivalent pounds per square inch	6.609	6.619	6.697	6.752	6.769	6.950	6.733	6.987	7.491
Total Head:									
9. By gauge on main and float, feet	170.335	166.339	169.377	169.548	172.542	181.729	171.640	171.710	164.565
10. By gauge on main and float, pounds per sq. in.	73.821	72.102	73.419	73.493	74.791	78.773	74.400	74.430	71.333

PERFORMANCE OF PUMP—*Continued.*

	First Day.	Second Day.	Third Day.	Fourth Day.	Fifth Day.	Sixth Day.	Average, Six Days.	Three-quarter Speed Test.	One half Speed Test.
Revolutions:									
11. Total number	55,931.	55,880.	57,109.	58,119.	60,532.	56,799.	57,381.83	21,650.	14,001.
12. Average number per minute	38.841	38.805	39.659	40.360	42.038	39.388	39.848	30.089	19.049
Plunger Speeds, Average, feet per minute:									
13. High-pressure pump	310.580	310.293	317.121	322.727	336.197	314.971	318.648	240.549	152.310
14. Intermediate pump	310.402	310.114	316.936	322.541	335.996	314.792	318.449	240.408	152.197
15. Low-pressure pump	310.301	310.013	316.830	322.436	335.890	314.687	318.349	240.326	152.133
16. Average for the 3 pumps	310.427	310.140	316.962	322.568	335.706	314.813	318.477	240.461	152.213
Velocity of Flow, feet per second:									
17. In suction main	3.329	3.320	3.390	3.450	3.609	3.376	3.416	2.578	1.632
18. In discharge main	3.375	3.373	3.447	3.508	3.653	3.423	3.463	2.614	1.656
19. Through vaive seats	1.314	1.313	1.342	1.366	1.423	1.333	1 349	1.018	.645
Capacity per Day, U. S. Standard Gallons:									
20. Number for plunger displacement at speed	15,421,100.	15,407,500.	15,746,000.	16,025,000.	16,690,500.	15,659,800.	15,891,750.	11,944,100.	7,868,490.
21. Number for plunger displacement, allowing 2 per cent. slip	15,113,400.	15,099,400.	15,431,700.	15,704,000.	16,356,700.	15,347,000.	15,575,200.	11,705,900.	7,711,160.
22. Contract requirement	15,000,000.	15,000,000.	15,000,000.	15,000,000.	15,000,000.	15,000,000.	15,000,000.		
23. Number in excess of contract requirement	113,400.	99,400.	431,700.	704,000.	1,356,700.	347,000.	575,200.		
24. Per cent. in excess of contract requirement	.756	.663	2.878	4.693	9.044	2.180	3.800		
Water Pressures, By Indicators, in Pump Cylinders, Average:									
25. Total head pumped against, high-pressure cylinder	75.490	73.332	75.788	75.081	70.631	80.967	76.080	75.908	79.994

PERFORMANCE OF PUMP—*Continued.*

	First Day.	Second Day.	Third Day.	Fourth Day.	Fifth Day.	Sixth Day.	Average, Six Days.	Three-quarter Speed Test.	One-half Speed Test.
Water Pressures: By Indicators, in Pump Cylinders, Average—*Continued.*									
26. Total head pumped against, intermediate cylinder	76.106	74.185	75.683	75.407	76.652	81.803	76.656	76.823	71.088
27. Total head pumped against, low-pressure cylinder	76.606	75.328	75.570	75.407	76.652	78.819	76.397	78.310	72.730
28. Total head pumped against, average of 3 cylinders	76.067	74.281	75.680	75.281	76.645	80.296	76.380	76.780	72.081
Work: Foot-pounds per hour.									
29. By gauge on main and float, total	913,140,000.	891,048,000.	927,288,000.	944,634,000.	1,001,238,000.	988,164,000.	944,252,000.	713,052,000.	432,741,000.
Horse-Power:									
30. By indicator, high-pressure pump	157.245	152.667	161.200	162.481	172.736	169.632	162.660	121.381	73.880
31. By indicator, intermediate pump	158.455	156.032	158.923	163.200	172.815	166.634	162.677	123.036	72.617
32. By indicator, low-pressure pump	159.455	156.717	162.373	165.616	173.446	175.645	165.542	126.362	74.284
33. By indicator, total for 3 pumps	475.155	465.416	482.496	491.297	518.997	511.911	490.878	371.679	220.781
34. By gauge on main and float	461.805	450.149	468.329	477.087	505.676	499.074	477.020	360.127	218.556
Economic Results:									
35. Duty, by gauge on main and float	149,520,000.	150,090,000.	150,908,000.	150,501,000.	152,325,000.	152,241,000.	150,930,800.	148,328,000.	142,287,000.
36. Contract requirement.	145,000,000.	145,000,000.	145,000,000.	145,000,000.	145,000,000.	145,000,000.	145,000,000.		
37. Number in excess of contract requirement	4,520,000.	5,090,000.	5,908,000.	5,501,000.	7,325,000.	7,241,000.	5,930,833.		
38. Per cent. in excess of contract requirement	3.11	3.51	4.07	3.79	5.05	4.99	4.086		
39. Duty, by indicators on pump cylinders	154,069,000.	154,620,000.	155,555,000.	154,518,000.	156,101,000.	155,184,000.	155,009,000.	153,011,000.	143,679,000.
40. Duty per million heat units	133,334,000.	138,842,000.	134,574,000.	134,209,000.	135,835,000.	135,759,000.	134,606,000.	132,209,000.	120,883,000.

Lines 3 and 4 show the water pressure in the discharge main as determined by gauges attached to the main beyond the pumps. Lines 5 and 6 show the vacuum in the suction main as determined by a gauge attached to the main just before it branched to the pumps; this gauge was read for only four days of the full-speed test. Lines 7 and 8 show the suction head in feet and pounds, which is the vertical distance between the centre of gauge on discharge main and the level of water in the well as determined by the float.

The difference between the quantities in lines 6 and 8 is accounted for by the head required to produce the velocity of flow (line 17) and the friction head in the suction main up to the branches. Lines 9 and 10 show the total head pumped against, line 10 being the sum of the quantities in lines 3 and 8, and line 9 being the equivalent head in feet.

Lines 11 and 12 show the total number of revolutions and the revolutions per minute. Lines 13–16 show the plunger speeds as determined by actual measurements. Lines 17–19 show the velocity of flow of the water through the suction and discharge mains and through the valve seats. Lines 20–24 show the capacity of the pump, the contract requirement, and the excess over the contract requirement.

Lines 25–28 show the total head pumped against in the pump cylinders, as determined by the indicator. These pressures have been determined from the average of about four selected cards for each day, taken at times when the speed and water pressure corresponded most nearly to the average for the day. Line 29 shows the work done by the pumps in foot-pounds per hour, and is the product of the quantities in lines 10 and 16 multiplied by 3 times the average net area of the plungers (221.372 square inches) and by 60 to reduce to the hour. Lines 30–33 show the indicated horse-power for each pump and the total for the three pumps, the mean effective pressures used being those of lines 25–28. Line 34 shows the horse-power from the pressure by gauge on main and float (line 10). This may also be found by dividing the quantities in line 29 by 1,980,000. Lines 35–38 show the duty computed under contract conditions and the excess of duty over the contract requirement. Line 39 shows the duty in the pump cylinders as determined by the indicator. Line 40 shows the duty per 1,000,000 heat units from the pressure by gauge on main and float. This latter duty may be found by

dividing the quantities in line 35 by the number of heat units in 1,000 pounds of steam above 100 degrees Fahr., and multiplying by 1,000,000; or by simply dividing the quantities in line 35 by the heat units in one-thousandth of a pound of steam.

Water Pressure.—In operating the engine at its full capacity, it was necessary to waste a considerable portion of the water to prevent the reservoir from overflowing. This was done by opening hydrants at different points in the city, and regulating the flow so as to maintain a proper level in the reservoir. In regulating the hydrants it was possible to effect a considerable variation of pressure against the pumps, as the discharge main to the reservoir was directly connected with a considerable part of the distributing system. At the same time the level of water in the well varied somewhat, owing to the fluctuations in the river level and to the presence of anchor ice at the intake cribs. The maximum and minimum pressures, with the corresponding plunger speeds, are shown in Table XXI.

TABLE XXI.

MAXIMUM AND MINIMUM WATER PRESSURES, IN FEET, BY GAUGE ON MAIN AND FLOAT, AND CORRESPONDING PLUNGER SPEEDS, IN FEET PER MINUTE.

	Full-speed Test.	¾-speed Test.	½-speed Test.
Pressure Heads, above Centre of Plungers.			
1. Maximum	170.57	161.35	148.66
2. Plunger speeds for heads in line 1	308.8	240.0	145.65
3. Minimum	145.20	149.81	144.0
4. Plunger speeds for heads in line 3	312.0	240.0	152.0
**Suction Heads, below Centre of Plungers.*			
5. Maximum	17.70	17.61	17.70
6. Plunger speeds for heads in line 5	312.0	241.6	158.4
7. Minimum	15.27	15.58	16.20
8. Plunger speeds for heads in line 7	313.6	241.6	152.0
Total Heads.			
9. Maximum	186.43	178.77	165.91
10. Plunger speeds for heads in line 9	308.8	241.6	150.4
11. Maximum	160.57	167.27	160 25
12. Plunger speeds for heads in line 11	312.0	240.0	152.0
13. Maximum suction heads	21.16	21.07	21.16

* Adding 3.46 feet to line 5 to obtain suction head from topmost discharge valve seat.

Plunger Speed.—Attention has already been called to the high plunger speed of these pumps when worked to their full capacity, an average of 318.5 feet per minute being maintained during the six days of the full-speed test. In general, the action was smooth and regular, and the valves operated satisfactorily. At certain times, however, the engine was observed to speed up suddenly for a portion of a revolution, and this action was accompanied by a violent slamming of the water valves until the engine governor had time to operate. This occurred most frequently at the hours of 8 A.M., noon, and 5.30 P.M., and was doubtless caused by the elevators, which were most in use at about those times. While the plunger speed is high, it is to be observed that the velocity of flow through the valve seats is not higher than good practice allows. The maximum and minimum plunger speeds, with the corresponding water pressures, are given in Table XXII.

TABLE XXII.

MAXIMUM AND MINIMUM PLUNGER SPEEDS IN FEET PER MINUTE, AND CORRESPONDING WATER PRESSURES IN FEET, BY GAUGE ON MAIN AND FLOAT.

	Full-Speed Test.	¾-Speed Test.	½-Speed Test.
1. Maximum plunger speeds	345.6	241.6	158.4
2. Pressure head above centre of plunger	156.57	153.11	147.34
3. Suction head below centre of plungers*	15.86	16.55	17.70
4. Total head, sum of lines 2 and 3	172.43	169.66	165.04
5. Minimum plunger speeds	307.2	240.0	145.6
6. Pressure head above centre of plunger	163.73	154.25	148.82
7. Suction head below centre of plunger	15.44	17.24	17.10
8. Total head, sum of lines 6 and 7	179.17	171.49	165.92
9. Maximum suction head	19.83	20.01	21.16

Capacity.—The capacity of the pump exceeded that required by the contract during every day of the full-speed test. On the fifth day, which was Sunday, when the elevator service was light, the pumps were allowed to work faster, and a capacity 9 per cent. greater than the contract requirement was obtained during twenty-four hours. For the entire six days of the full-speed test the capacity was 3.366 per cent. in excess of the contract requirement.

* Adding 3.46 feet to line 3 to obtain suction head from topmost valve seat.

Work.—The work in the pump cylinders is almost equally divided between the three pumps, the low-pressure pump doing about 2 per cent. more work than the other pumps.

By comparing the work done in the pump cylinders with that done in the steam cylinders, the average mechanical friction of the engine for the full-speed test is found to be 18.95 horse-powers, which is 3.71 per cent. of the indicated horse-power in the steam cylinders. This is certainly a very good showing, and is due to the very careful design of the pumping engine. Some of the features contributing to a favorable result may be mentioned: First, the greater part of the power is transmitted directly from the steam piston to the pump plunger; second, the connection between the piston and the flywheel is the simplest possible, and is arranged so that only the fluctuations of power are transmitted through it; third, the three cranks are set at angles of 120 degrees apart, so that the weight of fly-wheel required to give steady motion is much less than with cranks 180 degrees apart, as in many compound pumping engines.

In addition to these advantages, due to the design, the engine had the further advantages that it had been in use long enough to bring the bearings into good condition, and that during the tests the plunger packings were carefully watched and kept as loose as practicable.

By comparing the horse-power in the pump cylinder with that shown by the gauge on the pressure main and float, the average power lost during the full-speed test in fluid friction within the pump was 13.86 horse-powers, which is 2.72 per cent. of the indicated power in the steam cylinder.

The total power lost in the pumping engine was then 32.81 horse-powers for the full-speed test, which is 6.43 per cent. of the indicated horse-power. In other words, 93.57 per cent. of the power developed in the steam cylinder was delivered to the water outside of the pump.

Similar comparisons are not made for the $\frac{3}{4}$-speed and $\frac{1}{2}$-speed tests because of their shorter duration and the smaller number of readings taken.

Economic Results.—The duty requirement of the contract was very severe, inasmuch as the work done was to be measured outside of the pump cylinders, and the duty specified was at the same time unusually high. Notwithstanding this, the re-

quirement was more than fulfilled; the excess shown during the six days of the full-speed test being 4.086 per cent.

The average amount of steam delivered to the engine every twenty-four hours during the full-speed test, reduced to contract conditions, was (see Table XIV., line 8) 150,116 pounds. If the duty developed had been only that required by the contract, 156,250 pounds of steam would have been required to do the same work. During the test 7.126 pounds of water were evaporated per pound of coal under actual conditions. Under contract conditions the same amount of heat would have evaporated 7.019 pounds of water. To evaporate the additional 6,134 pounds of steam would, therefore, have required the burning of 873.8 additional pounds of coal, which, at $3 per ton, would cost $1.3107 per day. For 365 days the saving effected by the excess of duty over the contract requirement is $478.40. Reducing this to the capacity and head stipulated in the contract, the yearly saving in cost of coal by reason of the excess of duty over contract requirement would be $458.75. If 12 per cent. be allowed for interest and depreciation, the city could afford to invest $3,822.92 in order to effect a yearly saving of $458.75. In other words, the city could have afforded to pay $3,822.92 more for this pump than for one that would have just fulfilled the requirements of the contract.

For purposes of comparison, the economic results are brought together and stated in suitable terms in Table XXIII.

TABLE XXIII.

	Full-Speed Test.	¾-Speed Test.	½-Speed Test.
1. Pounds of steam from and at 212° Fahr. per I. H. P. per hour, in steam cylinders	14.247	14.805	15.487
2. Pounds of steam from and at 212° Fahr. per I. H. P. per hour, in pump cylinders	14.797	14.992	16.034
3. Pounds of steam from and at 212° Fahr. per net H. P. per hour, outside of pumps	15.227	15.473	16.197
4. Pounds of coal per I. H. P. per hour, in steam cylinders	1.748	1.816	1.900
5. Pounds of coal per I. H. P. per hour, in pump cylinders	1.815	1.839	1.967
6. Pounds of coal per net H. P. per hour, outside of pumps	1.868	1.898	1.987
7. Cost of pumping one million gallons 1 foot high, cents	1.179	1.198	1.254

It should be kept in mind that the coal used during the test was not selected coal, but was that regularly used under the boilers. If a superior quality of coal had been used under conditions giving an economic evaporation of 11.5 pounds of steam from and at 212 degrees Fahr. per pound of coal, results which have not infrequently been obtained in boiler trials, then the coal used per indicated horse-power per hour in the steam cylinders would have been 1.24 pounds, 1.29 pounds, and 1.35 pounds for the three tests, respectively. These results compare very favorably with the best which have been obtained in steam engines of similar size and capacity.

Indicator Cards.—Figs. 360, 361, and 362 show sample indicator diagrams from each of the three pump cylinders taken during each of the three tests.

In the diagrams of the full-speed test the suction line does not drop immediately to the point corresponding to the suction lift, but forms an easy curve, showing the effect of the air admitted through the air checks for cushioning. Naturally, the air required for cushioning was less at the lower speeds, and, in consequence, the suction lines are more nearly straight for the $\frac{3}{4}$-speed and the $\frac{1}{2}$-speed cards.

The rise in pressure at the end of the suction stroke, due to the fact that the inertia of the water carries it along when the plunger slows up, is also clearly shown and is greatest in the full-speed card.

The smoothness of the cards in the full-speed test indicates that the pumps were not being overworked.

Supplementary Tests.

Owing to the unusual completeness and duration of the main duty trial, opportunity was afforded for making various supplementary tests which show the performance of certain parts of the pumping engine and apparatus considered by themselves. The results obtained are of considerable interest, and are deemed worthy to be included in this general report.

Calibration of Water Meter.—The water meter was read at regular intervals throughout all the tests. No use has been made of those readings further than as a check upon the weights of feed-water. The results are introduced here as a record of the performance of this meter. The weight of one cubic foot by the meter has been found for each day of the full-speed test

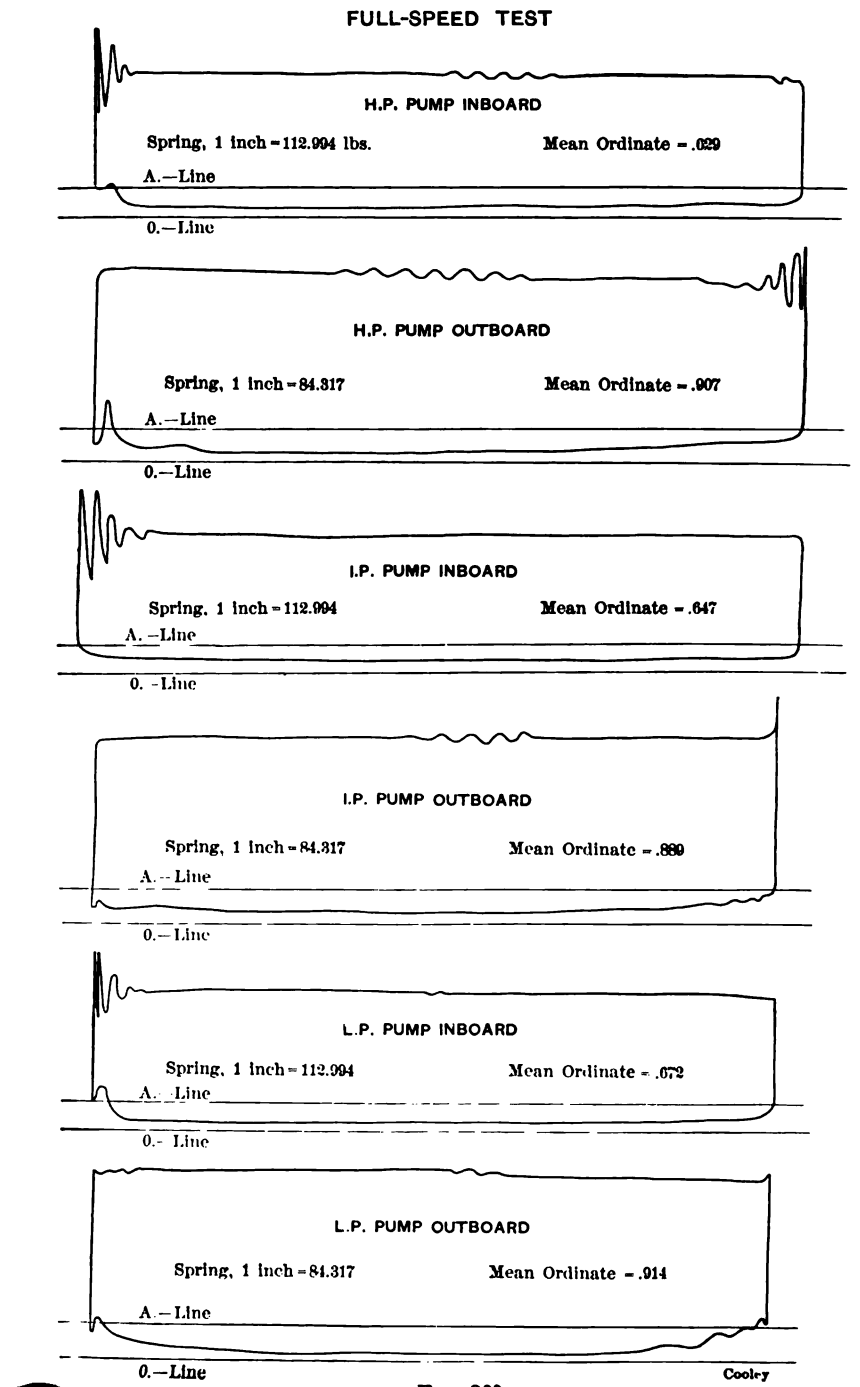
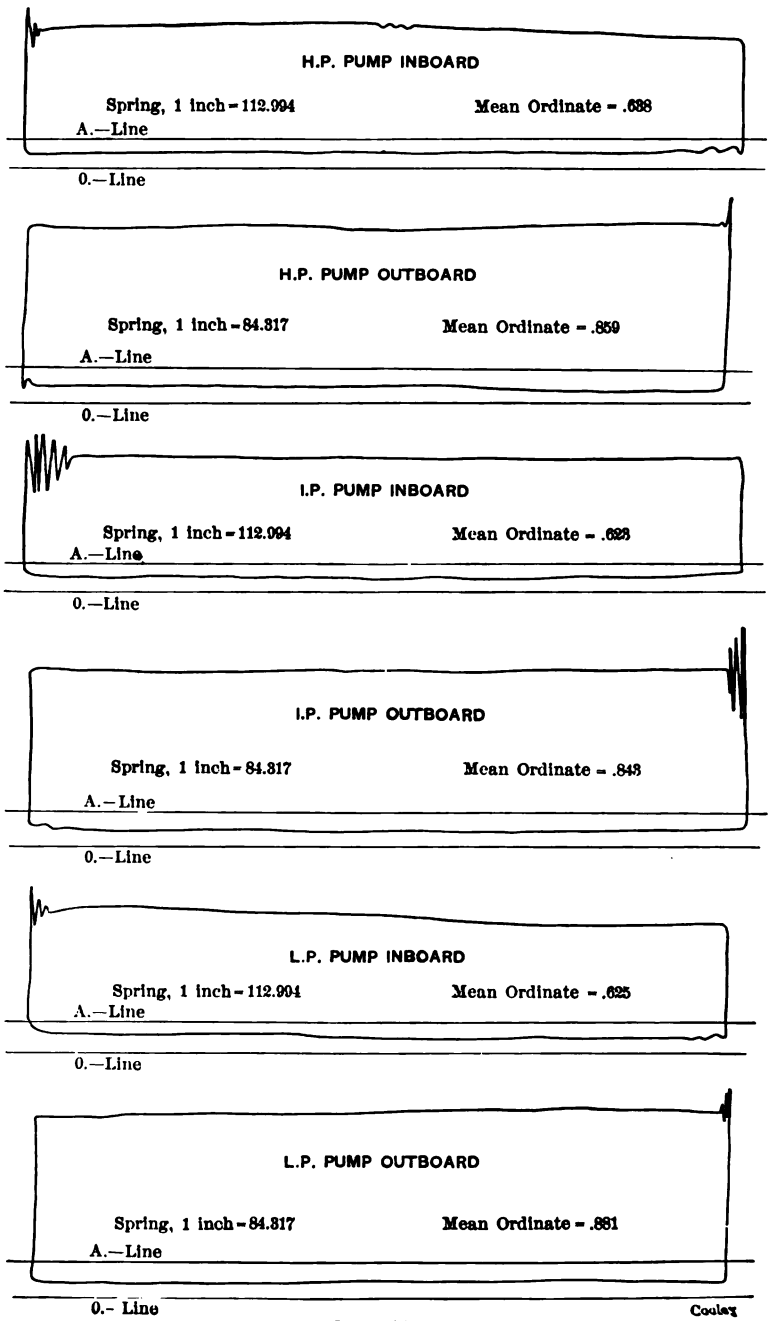

FULL-SPEED TEST
H.P. PUMP INBOARD
Spring, 1 inch = 112.994 lbs.
Mean Ordinate = .629
A.—Line
0.—Line
H.P. PUMP OUTBOARD
Spring, 1 inch = 84.317
Mean Ordinate = .907
A.—Line
0.—Line
I.P. PUMP INBOARD
Spring, 1 inch = 112.994
Mean Ordinate = .647
A.—Line
0.—Line
I.P. PUMP OUTBOARD
Spring, 1 inch = 84.317
Mean Ordinate = .889
A.—Line
0.—Line
L.P. PUMP INBOARD
Spring, 1 inch = 112.994
Mean Ordinate = .672
A.—Line
0.—Line
L.P. PUMP OUTBOARD
Spring, 1 inch = 84.317
Mean Ordinate = .914
A.—Line
0.—Line
Cooley

FIG. 360.

ONE-HALF-SPEED TEST



Cooley

FIG. 361.

THREE-QUARTER-SPEED TEST

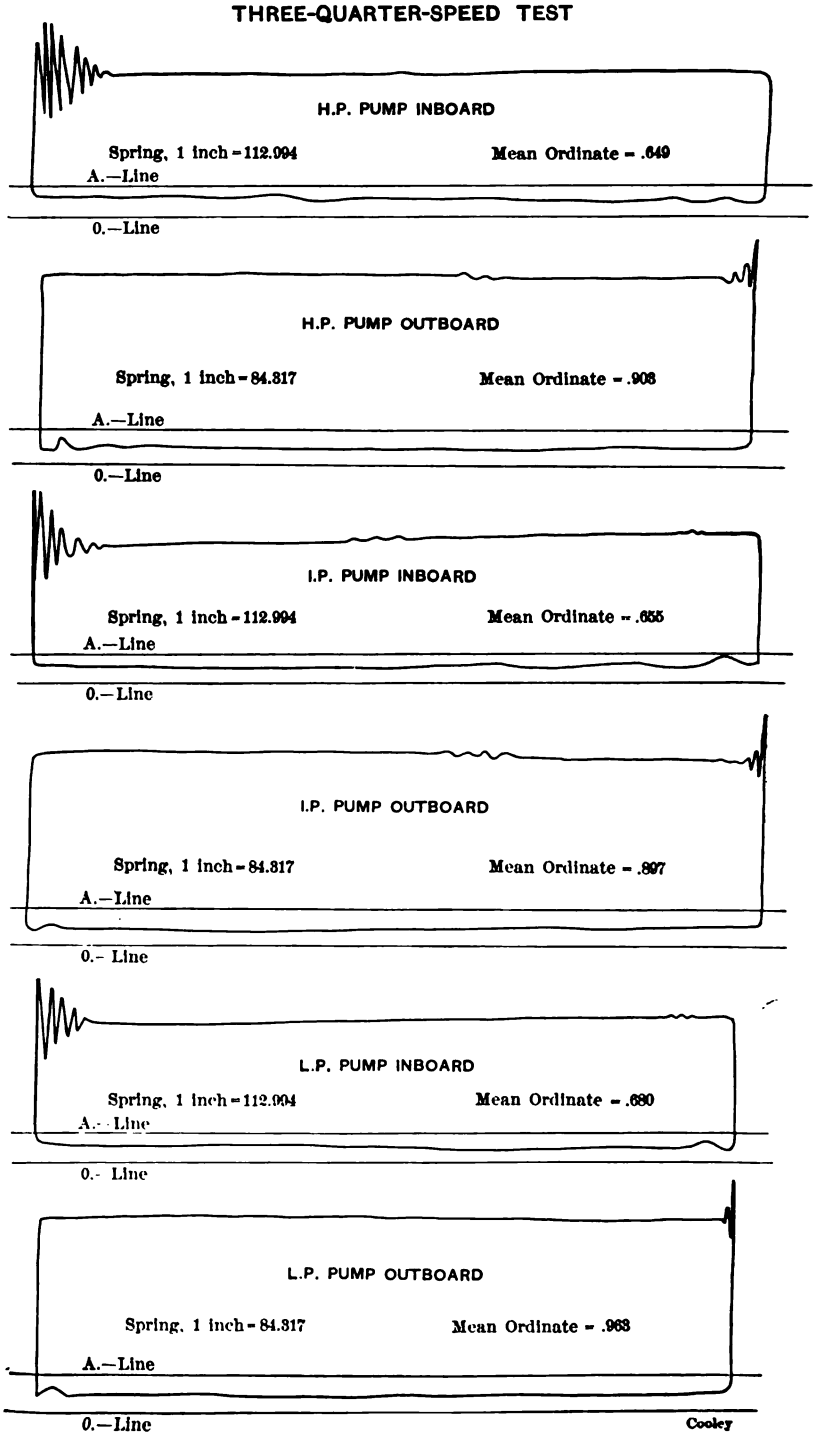


FIG. 382.

and for the tests at reduced speed. The results, which appear in Table XXIV., show a very satisfactory agreement for the different days. The average weight of one cubic foot for the entire time is 59.96 pounds. at a temperature of 117.14 degrees Fahr.

TABLE XXIV.

CALIBRATION OF WATER METER.

	Date, 1896.	Time.	Meter Reading.	Number of Cubic Feet.	No. Pounds of Water Weighed.	Weight of 1 Cubic Foot.	Average Temperature, Degs. Fahr.
	Feb.	A.M.					
1..	5	6.00	135,935				
2..	6	6.00	138,617	2,682	161,518.5	60.22	115.99
3..	7	6.00	141,223	2,606	157,166.8	60.31	116.22
4..	8	6.00	143,942	2,719	162,535.0	59.78	117.15
5..	9	6.00	146,705	2,763	165,469.0	59.89	118.45
6..	10	6.00	149,594	2,889	173,180.5	59.94	117.94
7..	11	6.00	152,450	2,856	170,726.5	59.78	117.24
8..	11	7.00	152,541				
		P.M.					
9..	11	7.00	153,625	1,084	64,742.0	59.73	118.08
10..	11	9.30	153,763				
		A.M.					
11.	12	9.45	154,490	727	43,405.0	59.70	115.85
12..	Totals and averages.....			18,326	1,098,743.3	59.96	117.14

Performance of Feed-water Heater.—The feed-water to the boiler all passed through the heater. The steam actually passing through the engine cylinders per hour is found by subtracting line 9 from line 6 in Table XIV. and dividing by 24. The temperatures of the exhaust steam, entering feed-water, and outgoing feed-water, are taken from lines 29, 34, and 32 of Table XIV. The results given in Table XXV. are calculated from the averages for the entire full-speed test.

TABLE XXV.

PERFORMANCE OF FEED-WATER HEATER.

1. Temperature of exhaust steam, degrees Fahr.....	120.267
2. Temperature of entering feed-water, degrees Fahr...	33.75
3. Temperature of outgoing feed-water, degrees Fahr.....	117.77
4. Pounds of exhaust steam through heater per hour.....	5,600.39
5. Pounds of feed-water through heater per hour.....	6,879.14
6. Heat units transmitted through heater per hour.....	577.916
7. Heating surface of heater, square feet.....	408.7
8. Heat units transmitted through heater per square foot of heating surface, per hour.....	1,414.03

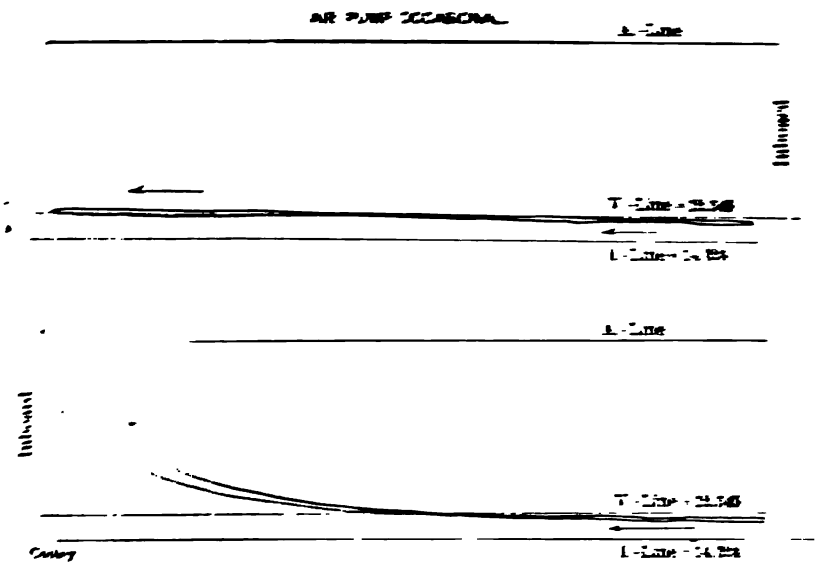


FIG. 383.

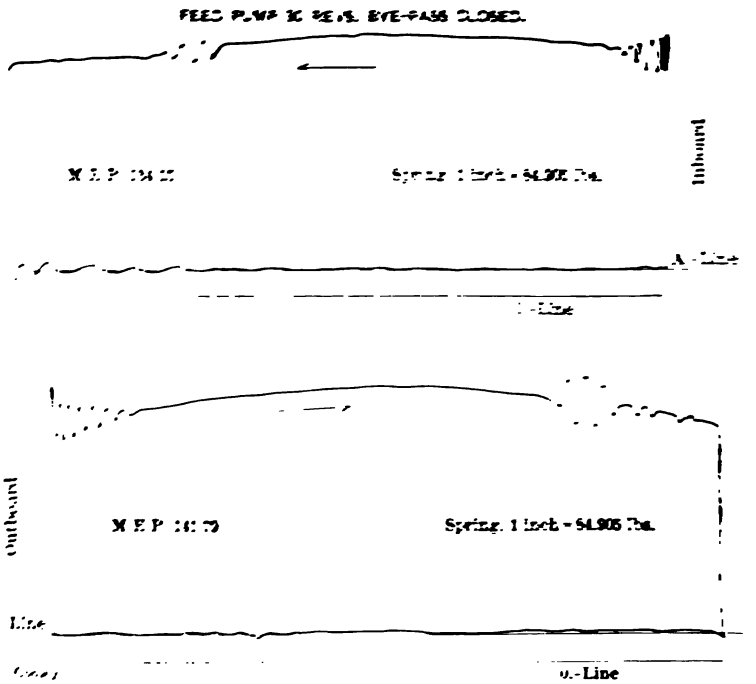


FIG. 384.

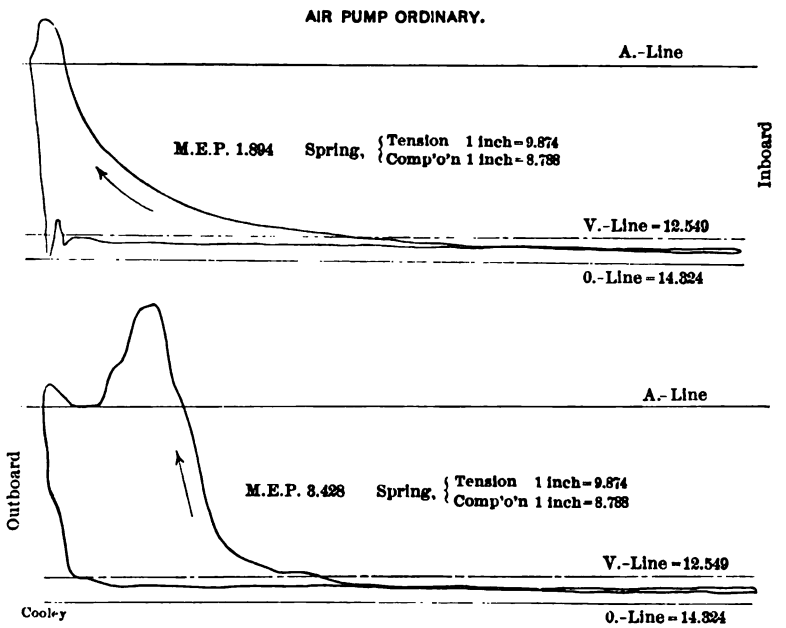


FIG. 365.

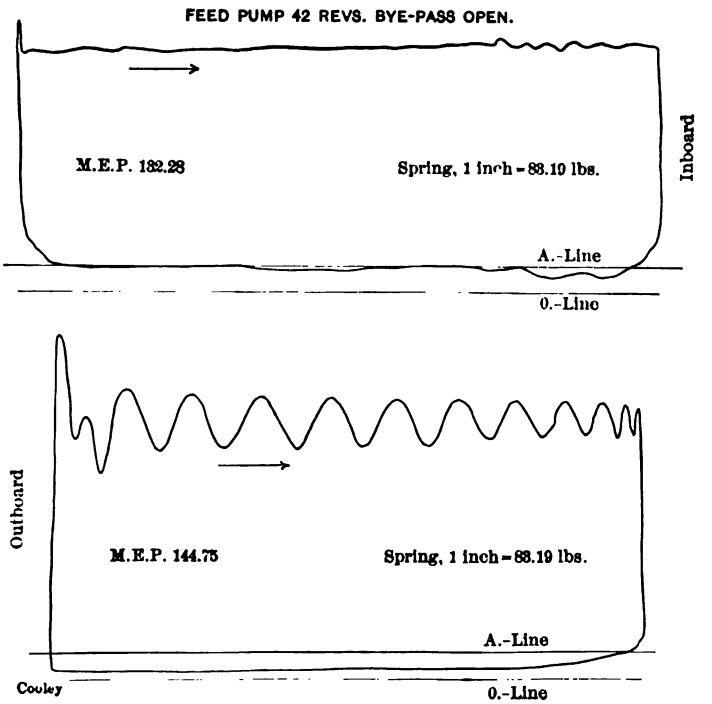


FIG. 366.

Performance of Feed Pumps.—Figs. 363 to 366 show sample indicator cards taken from the feed pumps, both with the bye-pass open and with the bye pass closed. The low suction line shown on the outboard feed-pump diagram seems to indicate that the suction valves of this pump stuck occasionally. The excessive value of the resistance of pump valves and feed-pipe line for the outboard pump (see line 16 of Table XXVI.) is doubtless also due to sticking of valves. The results of the feed-pump tests are given in Table XXVI.

TABLE XXVI.

PERFORMANCE OF FEED PUMPS.

	Inboard pump.	Outboard pump.
Indicated Horse-Power.		
1. Revolutions of engine, average per minute	42.036	42.036
2. Mean effective pressure, average of 3 cards, pounds per square inch	131.99	
3. Mean effective pressure, average of 6 cards, pounds per square inch	.....	139.47
4. Area of plunger (single acting), square inch	15.904	15.904
5. Stroke of plunger, inches	8	8
6. Indicated horse-power	1.783	1.884
7. Total indicated horse-power of both pumps	.....	3.667
8. Total indicated horse-power of engine	.....	537.224
9. Per cent. of indicated horse-power of engine shown in both feed pumps	.....	0.68
Resistance of Valves and Feed-pipe Lines (pounds per square inch).		
10. Average mean effective pressure	135.126	136.825
11. Elevation of water in boiler above centre of plunger displacement (16.824 feet)	7.218	7.218
12. Elevation of water in feed tank above centre of plunger displacement (3.437 feet)	1.490	1.490
13. Elevation of water in boiler above water in feed tank (13.387 feet)	5.728	5.728
14. Average steam pressure in boiler	124.876	124.876
15. Net head against feed-pump plungers	130.604	130.604
16. Resistance of pump valves and feed-pipe line	1.385	8.872

A SUPPLEMENTARY TEST.

From cards taken by Chief Engineer E. A. Bates, August 19, 1896.

	Inboard pump.	Outboard pump.
Resistance of Valves and Feed-pipe Lines (pounds per square inch).		
1. Average mean effective pressure	134.999	136.697
2. Difference of level between water in hot well and boiler (14.424 feet)	6.188	6.188
3. Average steam pressure in boiler	127.833	127.75
4. Net head against feed-pump plungers	134.021	133.938
5. Resistance of pump valves and feed-pipe line	.978	2.759

Performance of Air Pumps.—A series of indicator cards were taken from the air pumps February 9th, the fifth day of the full-speed test. The specimen diagrams which appear on Plate XI. show that the greater amount of work is done by the outboard pump or pump furthest from the condenser. Occasionally the diagram from the inboard pump showed that its bucket valves failed to open as the suction and delivery lines were coincident. This pump being nearest to the condenser, received most of the air and but little of the water, which would explain this action.

The dimensions of the air pumps appear in Table XXVII. and the performance in Table XXVIII. The horse-power and the friction of valves and passages have been obtained from averages of 10 cards for the inboard and 8 cards for the outboard pump. The vacuum in the condenser was observed simultaneously with the taking of the cards. The centre of the 12-inch discharge pipe is 7 inches above the top of the delivery-valve plate, and it is assumed that the water flowed in this pipe at a depth of 3 inches. This would give a head of 4 inches of water above the plate.

Line 7 of Table XXVIII. shows 0.79 indicated horse-power for the inboard and 1.486 for the outboard pump, the total for both pumps being 2.276, or 0.424 per cent. of the total indicated horse-power of the engine. Line 21 shows a difference of 0.572 pound per square inch between the vacuums in the condenser and in the air pumps. This difference represents the pressure required to lift the bucket valves, plus the frictional losses of the water and the passages. Line 25 shows a corresponding

resistance of 2.003 pounds per square inch for the delivery valves.

Line 13 shows an average absolute pressure in the condenser of 1.784 pounds per square inch, and line 3 a temperature of 96.44 degrees Fahr. This temperature corresponds to a vapor pressure of 0.846 pound per square inch. The difference between the total pressure 1.784 and the vapor pressure 0.846, or 0.938 pound per square inch, is due to the presence of air and is equivalent to a loss in vacuum of 1.91 inches. This loss, while not excessive, is larger than it should be by at least 1 inch. An increase of 1 inch in the vacuum would add practically one-half pound to the effectiveness of the low-pressure cylinder and increase the duty sensibly.

TABLE XXVII.

DIMENSIONS OF AIR PUMPS.

1. Number of single-acting air pumps	2
2. Diameter of buckets, inches	17
3. Stroke of buckets, inches	18
4. Diameter of bucket rod, inches	2
5. Net area of each bucket, square inches	223.84
Bucket Valves rubber disks:	
6. Number of valves, each pump	5
7. Diameter of valves, inches	5.875
8. Area through each valve seat, square inches	12.600
9. Total area through valve seats, square inches	63.000
10. Ratio of valve area to bucket area	0.281
Delivery Valves, rubber disks:	
11. Number of valves, each pump	6
12. Diameter of valves, inches	6.625
13. Area through each valve seat, square inches	18.700
14. Total area through valve seats, square inches	112.200
15. Ratio of valve area to bucket area	0.501

TABLE XXVIII.

PERFORMANCE OF AIR PUMPS.

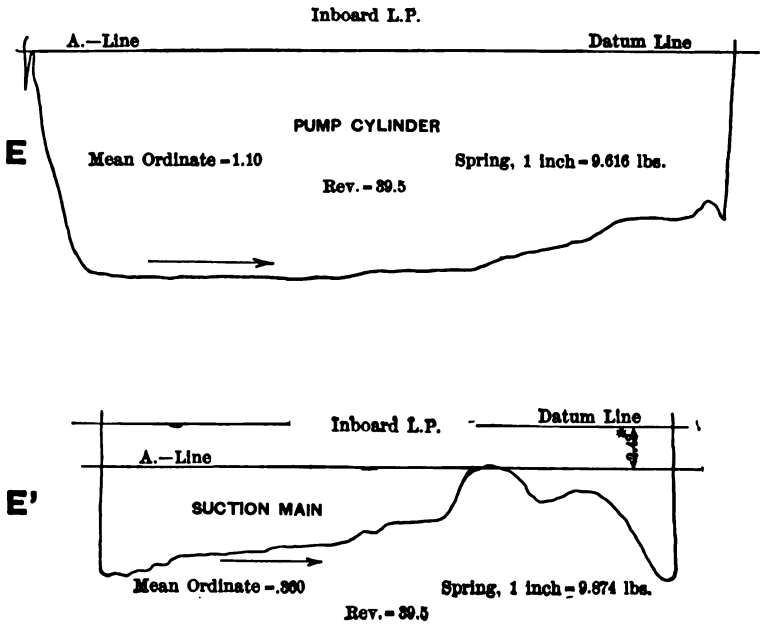
1. Revolutions of engine, average per minute	42.036
2. Temperature of injection water, degrees Fahr.	33.92
3. Temperature of discharge water, degrees Fahr.	96.44
4. Vacuum in condenser, inches	25.58
5. Barometric pressure, inches	29.22

Indicated Horse-power:	Inboard.	Outboard.
6. Mean effective pressure, pounds per square inch	1.848	3.474
7. Indicated horse-power	0.790	1.486
8. Total indicated horse-power of both pumps	2.276	
9. Total indicated horse-power of engine	537.23	
10. Per cent. of indicated horse-power of engine shown in air pumps	0.424	
Friction of Bucket Valves, pounds per square inch, average:		
11. Barometric pressure (29.22 inches)	14.323	14.323
12. Vacuum in condenser (25.56 and 25.6 inches)	13.529	13.549
13. Pressure in condenser	1.794	1.774
14. Vacuum in air pumps at middle of suction stroke	13.033	13.143
15. Pressure in air pumps at middle of suction stroke	1.290	1.181
16. Vacuum in air pumps at end of suction stroke	13.063	13.206
17. Pressure in air pumps at end of suction stroke	1.260	1.117
18. Vacuum in air pumps, average of lines 14 and 16	13.048	13.174
19. Pressure in air pumps, average of lines 15 and 17	1.275	1.149
20. Friction or excess of pressure in condenser above pressure in air pumps, lines 12 and 18, also lines 13 and 19	0.519	0.625
21. Average friction for both pumps	0.572	
Friction of Delivery Valves, pounds per square inch, average:		
22. Pressure above atmosphere in air pump on delivery stroke	2.004	2.59
23. Head of water above delivery-valve plate, 4 inches	0.144	0.144
24. Friction or excess of pressure in air pumps above head of water on delivery valves	1.860	2.146
25. Average friction for both pumps	2.003	

Friction of Pump Valves and Passages.—In order to obtain the friction of the pump valves and passages, simultaneous indicator cards were taken from the pump cylinders and the water mains. Specimen diagrams show Figs. 367 and 368, where cards are marked with the same letter when taken simultaneously.

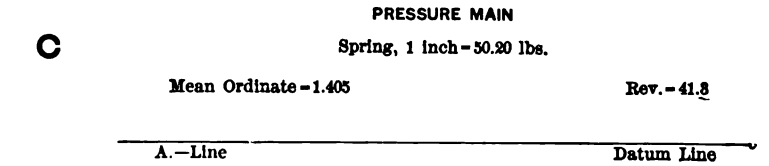
The friction of the discharge valves was determined only for the high-pressure pump at full speed, and is given in Table XXIX. The friction of the suction valves was determined for each of the three pumps and during each of the three tests, the results being given in Tables XXIX., XXX., and XXXI.

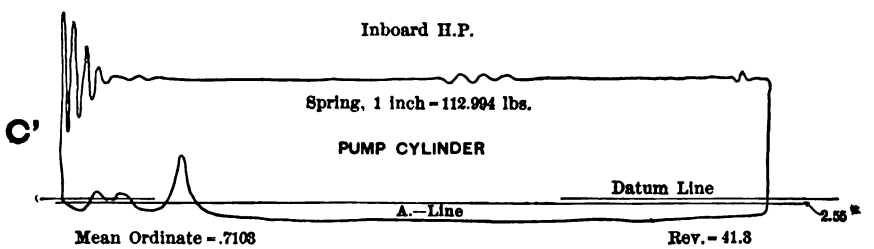
Figs. 367 to 372 show sets of three simultaneous cards taken, one from the pump cylinder, one from between the air chambers above the discharge valves, and one from the suction air chamber between the pump ends. Cards C and C^1, Fig. 368, are simultaneous cards from the pump cylinder and the discharge main, similar to those from which the friction of the discharge valves has been calculated. Card D was taken by moving the indicator

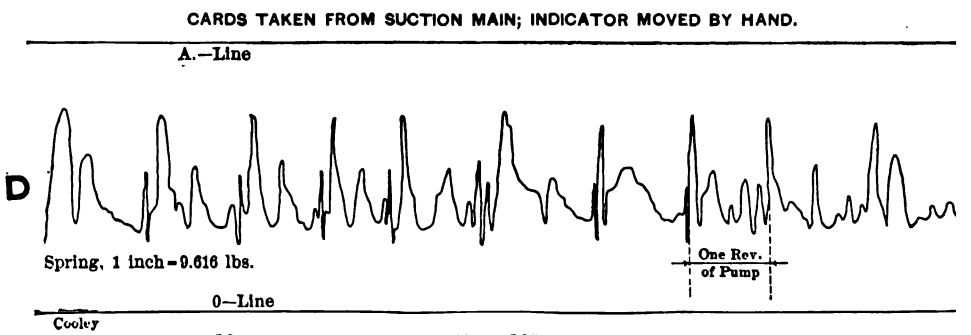


Cooley

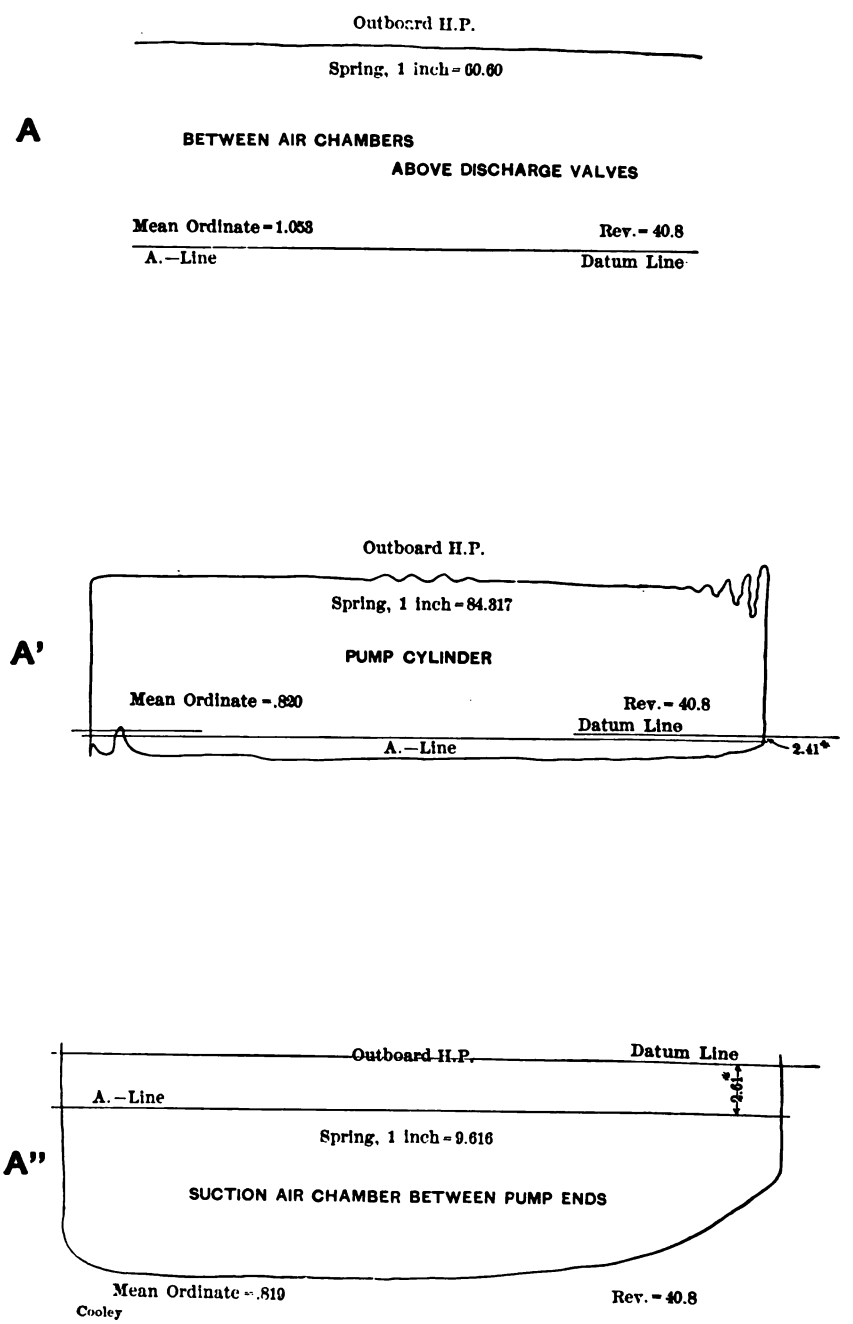
FIG. 387.


C
PRESSURE MAIN
Spring, 1 inch = 50.20 lbs.
Mean Ordinate = 1.405
Rev. = 41.8
A.—Line
Datum Line


C'
Inboard H.P.
Spring, 1 inch = 112.994 lbs.
PUMP CYLINDER
Datum Line
A.—Line
2.55
Mean Ordinate = .7103
Rev. = 41.8

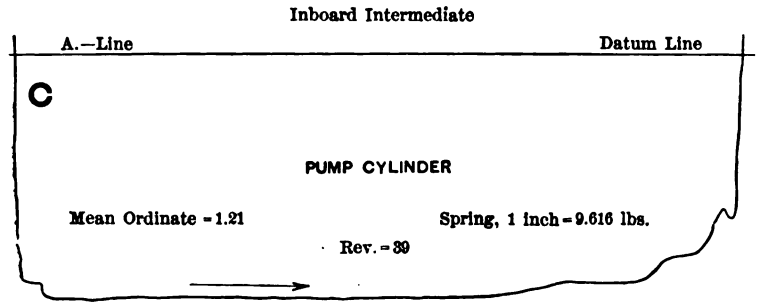

CARDS TAKEN FROM SUCTION MAIN; INDICATOR MOVED BY HAND.
A.—Line
D
Spring, 1 inch = 9.616 lbs.
One Rev. of Pump
0—Line
Cooley

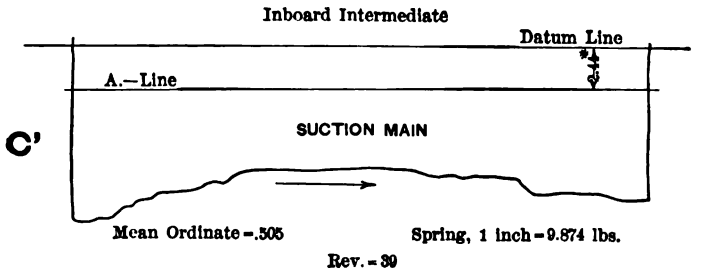
70 FIG. 368.

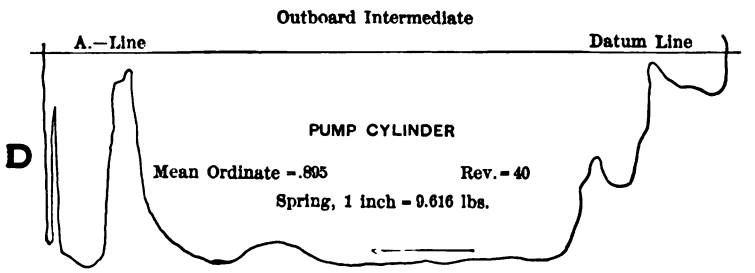


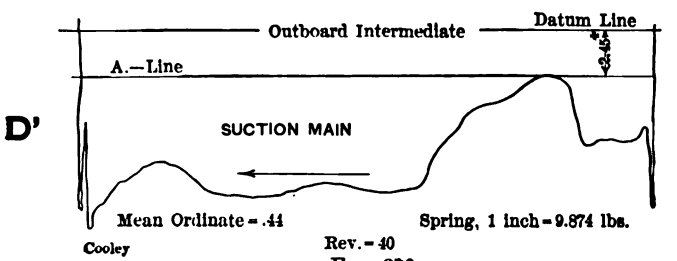
Cooley

FIG. 369.



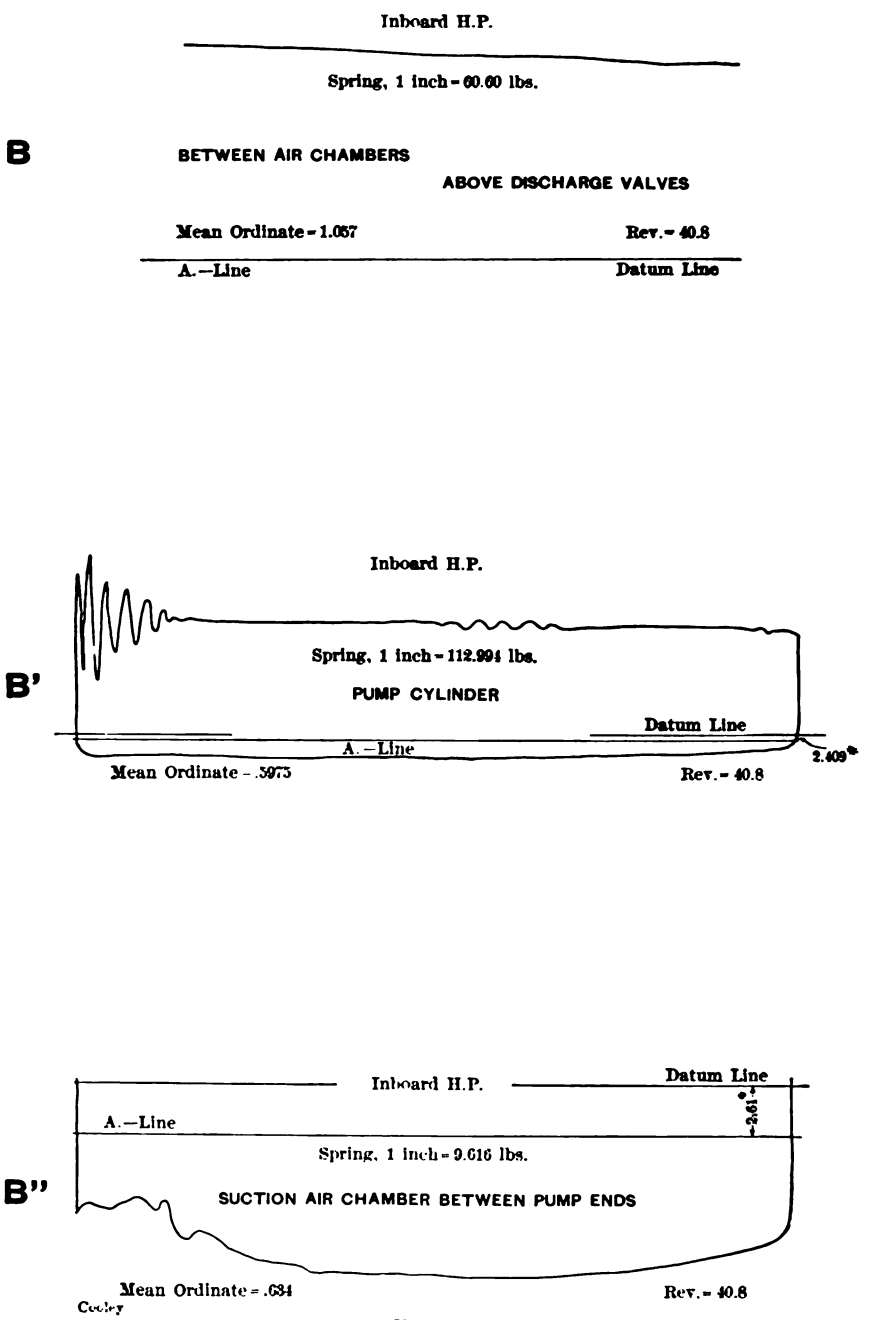






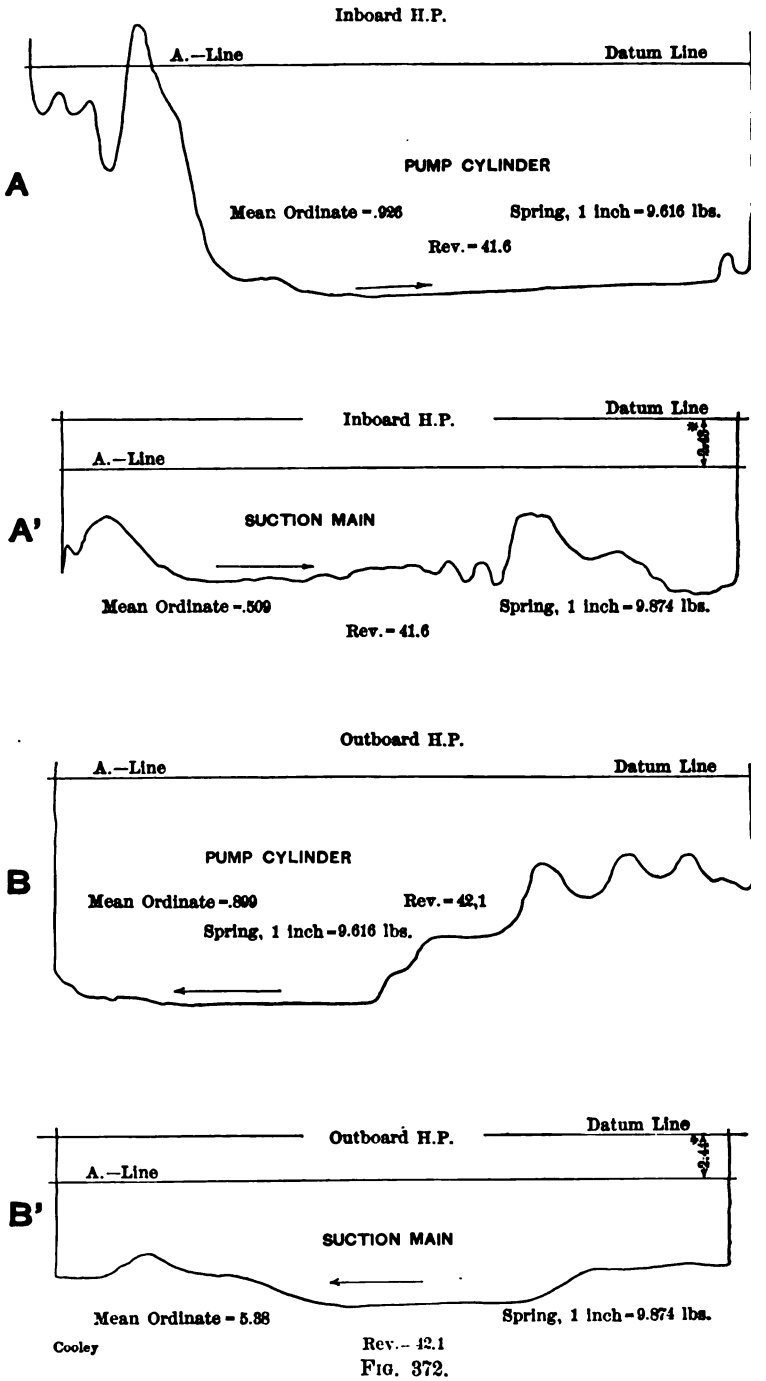
Cooley

FIG. 370.



Cooley

FIG. 371.



Cooley

FIG. 372.

drum by hand, so that equal horizontal distances represent approximately equal intervals of time.

In all of the calculations for valve friction proper allowance has been made for the difference in elevation of the indicator pistons.

TABLE XXIX.

VALVE FRICTION AT FULL SPEED.

(Each reading a mean of five cards.)

Discharge Valves, mean effective pressures above atmosphere, pounds per square inch :		
1.	High-pressure pump, inboard	65.872
2.	Simultaneous pressure in discharge main	64.237
3.	Friction of high-pressure inboard discharge valves	1.135
4.	High-pressure pump, outboard	65.929
5.	Simultaneous pressure in discharge main	64.094
6.	Friction of high-pressure outboard discharge valves	1.835
7.	Average friction of high-pressure discharge valves	1.485
Suction Valves : mean effective pressures below atmosphere, pounds per square inch :		
8.	High-pressure pump, inboard	9.656
9.	Simultaneous pressure in suction main	7.771
10.	Friction of high-pressure inboard suction valves	1.885
11.	High-pressure pump, outboard	8.768
12.	Simultaneous pressure in suction main	7.754
13.	Friction of high-pressure outboard suction valves	1.014
14.	Intermediate pump, inboard	11.381
15.	Simultaneous pressure in suction main	7.314
16.	Friction of intermediate inboard suction valves	4.067
17.	Intermediate pump, outboard	8.405
18.	Simultaneous pressure in suction main	6.803
19.	Friction of intermediate outboard suction valves	1.602
20.	Low-pressure pump, inboard	10.013
21.	Simultaneous pressure in suction main	6.134
22.	Friction of low-pressure inboard suction valves	3.879
23.	Low-pressure pump, outboard	8.821
24.	Simultaneous pressure in suction main	7.888
25.	Friction of low-pressure outboard suction valves	.933
26.	Average friction of inboard suction valves	3.277
27.	Average friction of outboard suction valves	1.183
28.	Average friction of all suction valves	2.230

TABLE XXX.

VALVE FRICTION AT THREE-QUARTERS SPEED.

(Each reading a mean of three cards.)

Suction Valves, mean effective pressures below atmosphere, pounds per square inch :

1.	High-pressure pump, inboard	7.939
2.	Simultaneous pressure in suction main	7.622
3.	Friction of high-pressure inboard suction valves	.317
4.	High-pressure pump, outboard	8.006
5.	Simultaneous pressure in suction main	7.423
6.	Friction of high-pressure outboard suction valves	.583
7.	Intermediate pump, inboard	8.285
8.	Simultaneous pressure in suction main	7.292
9.	Friction of intermediate inboard suction valves	.993
10.	Intermediate pump, outboard	8.167
11.	Simultaneous pressure in suction main	7.385
12.	Friction of intermediate outboard suction valves	.782
13.	Low-pressure pump, inboard	8.506
14.	Simultaneous pressure in suction main	7.186
15.	Friction of low-pressure inboard suction valves	1.320
16.	Low-pressure pump, outboard	8.211
17.	Simultaneous pressure in suction main	7.153
18.	Friction of low-pressure outboard suction valves	1.058
19.	Average friction of inboard suction valves	.877
20.	Average friction of outboard suction valves	.808
21.	Average friction of all suction valves	.842

TABLE XXXI.

VALVE FRICTION AT ONE-HALF SPEED.

(Each reading a mean of three cards.)

Suction Valves, mean effective pressures below atmosphere, pounds per square inch :

1.	High-pressure pump, inboard	8.397
2.	Simultaneous pressure in suction main	7.888
3.	Friction of high-pressure inboard suction valves	.509
4.	High-pressure pump, outboard	8.211
5.	Simultaneous pressure in suction main	7.884
6.	Friction of high-pressure outboard suction valves	.327
7.	Intermediate pump, inboard	8.724
8.	Simultaneous pressure in suction main	8.016
9.	Friction of intermediate inboard suction valves	.708
10.	Intermediate pump, outboard	8 693

11. Simultaneous pressure in suction main	7.980
12. Friction of intermediate outboard suction valves	.713
13. Low-pressure pump, inboard	8.981
14. Simultaneous pressure in suction main	8.085
15. Friction of low-pressure inboard suction valves	.896
16. Low-pressure pump, outboard	8.714
17. Simultaneous pressure in suction main	8.015
18. Friction of low-pressure outboard suction valves	.699
19. Average friction of inboard suction valves	.704
20. Average friction of outboard suction valves	.580
21. Average friction of all suction valves	.642

DISCUSSION.

Prof. F. L. Emory.—I would like to ask concerning the combined cards in the papers which have been presented, whether they were drawn by following one charge of steam through the cylinders or whether they are the averages of the performances of the engine throughout the tests.

Mr. Wagner.—The data for the combined cards were selected by the use of ten cards, which were as nearly average cards as could be obtained with the very constant load on the engine. The cards which were simultaneous, were combined together to form the combined card presented in the paper, but, of course, the individual cards were not simultaneous. In any case they should be successive, to follow one charge of steam through the successive cylinders, rather than simultaneous cards from the three cylinders at one instant.

Mr. F. A. Halsey.—There has been considerable interest in connection with the question of friction of these engines. I am led to remark that I have little faith in friction tests from the indicator card, for the reason that the indicator as applied to the water ends and the steam cylinder is under entirely different conditions as regards heat. This is true, also, of tests of air compressors. If it should happen that the indicator card from the steam ends was a little too large, while the indicator card from the water end was a little too small, the quantities in question are so large that to determine the friction by this gives a result far from accurate. It may be in this case that the springs were calibrated for their respective conditions, but even if this were true for this case, it is the fact that in most other cases they are not so calibrated. I consider the inside of a cylinder is no

proper place for an indicator spring. I much prefer the design made in England by Lloyd Brothers, who take the spring out of the cylinder and make it in the form of a sugar tongs, so that the condition of the spring as regards heat is always the same, whether the instrument is used on hot or cold media.

No. 864.*

EDUCATION OF MACHINISTS, FOREMEN, AND MECHANICAL ENGINEERS.

BY M. P. HIGGINS, WORCESTER, MASS.

(Member of the Society.)

NOTE.—The paper presented herewith is a supplement of the original paper, No. 850, presented first at the meeting of the Society in December, 1899. It is published on page 646 of the current volume.

The importance of the subject induced its second presentation at the Cincinnati Meeting, with the rejoinder of its author to the discussion presented at the first meeting, as the starting point for the discussion at the second, or Cincinnati Meeting. It is now published with the discussion as held at the Cincinnati Meeting, with the author's final rejoinder. Readers interested in the subject treated in Mr. Higgins's paper should be careful to consider both presentations.

THE expert opinion and valuable suggestions presented by the members of this Society in the discussion upon the subject of the "Education of Machinists, Foremen, and Mechanical Engineers," at the last meeting, proved to be of such interest and value that there has been a general demand that the discussion be continued at this time. Many phases of the subject, which I had left to be enlarged upon in the "author's closure," have been so much more clearly and forcibly put by the gentlemen who have contributed to the discussion, than I could have done, that I am largely relieved from presenting a rebuttal.

Several remarks in the discussion indicate that my conception of the length and breadth covered by the term "machinist" is not fully understood, and needs some explanation. A clear comprehension of what a machinist is to-day in the best American sense, and of the dignity and importance of his calling, is necessary to a consistent understanding of my subject and the scheme proposed for the half-time school. It is upon such an understanding that my faith in the same fundamental training for the machinist and engineer is based.

---

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

The Dignity and Importance of the Mechanic's Calling.

It is quite evident that there is no general deep appreciation of the dignity and importance of the position of the mechanic. If I am able to express to you how I regard it, I hope to show that there is no occupation that is better fitted to develop character and elevate mankind than that of the mechanic; that there is good reason why the machinist's trade should be elevated and exalted; and that there are greater inducements for having our sons learn a trade than is generally recognized.

I am persuaded in my own mind, after years of thought and observation, that there are very sound reasons for assigning to the position and calling of the mechanic a certain elevation and superiority above that of any other profession. This sentiment was voiced several years ago by such an eminent educator as the late Prof. John Woodman, of Dartmouth College. "For more than a century past the three learned professions, so-called, have stood preëminent: the doctor, the lawyer, and the minister have been respected and honored so generally and so highly that the best ambition of the best young men has been stimulated almost entirely in this direction, and our country owes much that is most precious in our civil and social life to the influence of these noble professions. What is it that has set these callings on high? Is there anything in the *nature of the work* that makes it better and more honorable? Nothing, for at different times and in other countries all the other prominent pursuits of men: agriculture, the mechanic arts, the fine arts, and so on, have taken the first rank. What then is the cause? Is it not simply this? The leading occupations God has put before men for employment, discipline, and duty, are in themselves alike honorable, and it is the culture, character, and excellence of the man himself that elevates his special pursuit."

So far as the kind of work affects the character of men, nothing in the line of human activity is so well calculated to develop the imagination in the direction of the creative powers of the human mind as the designing and making of machinery. This is a very lofty claim for the mechanic, but with all thoughtfulness I submit these two questions for your consideration, viz.: (1) Is there any human power more exalted in its nature and character than the creative power? (2) Is there any work of mankind which so much demands and expands the creative powers as the making and developing of machinery?

No other branch of human knowledge has made such wonderful advances as has mechanical engineering within the past century. So much I have said, with the sincere belief that I have not overstated it, in order to show that we have abundant grounds for the highest appreciation for the calling of a mechanic. In the term mechanic I include all manufacturers, engineers, and others engaged in the production of things useful.

The Broad Meaning of the Term "Machinist."

Dr. Thurston says: "The training of the machinist, further, for the purposes of the engineer, must be supplemented by that of the wood worker and pattern maker, of the moulder and founder, of the blacksmith, of the tool dresser, and of the draughtsman and designer as well. All are requisite to the engineer."

This I agree with most heartily, but I would add that, in my opinion, a knowledge of all of these is requisite to a machinist in the broadest American sense. It is this high type of mechanic, which I have known intimately by experience, that justifies this meaning of the term machinist, as I have used it in the consideration of this subject. A British mechanic is only one of these. A British machinist, or "fitter," is a very narrow mechanic, and while he may be thorough in his one line, he is a very narrowly trained man as compared with the best American type, such as many of us have known, and such as the half-time school system will aim to produce.

From the nature of things, the machinist's trade, in the American sense, is the broadest of all trades, and it is also the basis of many, if not all, other trades. A good machinist of this type is frequently able to do good work at each of the other trades mentioned by Dr. Thurston as being requisite to an engineer, but generally a good workman in either of the other trades is unable to do work with any credit in a machine shop.

The object of calling attention to these truths is to show what kind of machinists are in mind when we refer to a schooling intended to train machinists, foremen, and mechanical engineers, and also to show why the machine shop is a most important and effective place for the fundamental training of engineers, as well as of all grades of men below the engineer, and why the machinist's trade is preëminently the trade which should first be developed and advanced by trade schools of a high order, accompanied by an appropriate scientific and general education and general

culture. This, I claim, can be done by combining the high-school course, somewhat modified, with the best possible instruction and practice in the school shops. After this most promising undertaking has succeeded, as I think from its nature and importance it is likely to succeed, other trades of lesser breadth and scope may be taught in like manner, but probably to a class of boys of less extended capacity or less ambition than it is possible to select and to enlist in the proposed half-time school to make machinists, foremen, and mechanical engineers.

The Requirements of the Machinist of To-day.

Prof. D. S. Kimball, of Sibley College, says: "I do not believe that the manual skill required of the machinist to-day is as high as that of thirty years ago." And this view has been taken by a writer in the *Railroad Gazette* of recent date. Our system of automatic machinery and division of labor by piece-work is suggested, very falsely I think, to sustain this view.

In reply to such a claim, I would say we shall certainly suffer great loss if we are allowed to be led into any such error as this. Automatic machinery, systems of piece-work, and division of labor do not and will not lower the requirements of the machinist's skill and knowledge. Although these changes enable the manufacturer to make a larger use of unskilled laborers as operatives, yet, on the other hand, the requirements for skill of the machinist have been raised, not lowered. He must think more accurately, make more exact measurements, work hardened steel parts to a degree of precision which was not thought of by the old-time machinist. The skill and scientific knowledge regarding cutting tools and tempering many kinds of tools and parts of machines has made very wonderful advances within our memory. Take, for instance, a single tool for illustration, the die for screw-thread cutting. The old tool was properly called a "jam-plate." The screw-thread was made by jamming the metal into the form of a thread. There was not then knowledge enough in the shops to lead to the conception of chasing a clean, full thread with a single cut with the die, and removing free, continuously cut chips from the iron or steel. Such attempts were then generally confined to jamming a poor thread on a small bolt by repeated passes. Now we see practically perfect, full, clean threads cut on rods of any length and up to two inches or more in diameter. This achievement is entirely due to the advanced skill and understanding of the machinist.

We must not be misled by the observation of automatic machinery turning out the most exact work with such rapidity when operated by a rough boy called in from the streets or farm. In addition to the superior skill required of the machinist to construct these automatic machines, we should remember that it is not safe to run them a single day without the presence of a skilled machinist, who may be called upon to make an adjustment, to detect a mysterious fault in its action, to adapt it to a new form of product, or to refit or make a new member requiring exactness and an accuracy of measurement that would have been impossible to the ordinary machinist of thirty years ago.

I am of the opinion that if all our present improved automatic machinery and refined shop instruments and machine tools could have been delivered and set up in the machine shops of thirty years ago, there would not then have been skill enough to make good use of them.

Thus the use of automatic machinery, so marvellous in extent and accomplishment, may lead one to a false conclusion regarding the requirements of our future machinists. The field of the machinist has broadened so greatly that he does not find himself replaced, as the newspaper compositor is replaced, by the linotype operator, but he is called upon to construct hundreds of new machines, to make new products. If an automatic bolt cutter, for example, relieves him of a portion of his former duty, he is still needed in making the machines which are replacing hand labor in other trades. He is making automatic shoe machinery, automatic typesetting machinery, automatic sewing machines, automobiles, and hundreds of machines used to fill wants not known or felt fifty years ago. He is replacing the skill in the other arts and manufactures by his own skill.

Such is the superior skill required of the machinist to-day, in order to keep our highly organized machines working properly, that the training of machinists becomes of the greatest moment in the question of national mechanical supremacy. While France, Switzerland, and Germany are giving training in development of skill among all classes of their mechanics below the mechanical engineer, we cannot fall into greater danger than that of feeling secure and confident that automatic machinery, shop systems, or what not will take the place of mechanical skill and scientific shop training of our machinists. And we must not forget also that the perfection of our machine tools and of our small tools

and of our automatic machinery, which have been evolved, invented, made, improved, and perfected by machinists, is due to them rather than to any other class of men in the line of mechanical industry. Furthermore, this high development is the direct result of the personal observation and experience of skilled machinists in the actual performance of work by the old and poorer methods. Through their daily experience they felt the need and met it.

Just as sure as the American mechanic sits down to smoke complacently, because he has an automatic machine which is kept going by a thoughtless operative, just so sure will he find himself behind in the race for mechanical supremacy.

Why are American Boys not Learning Trades?

The fact that so very few of our best American boys are learning trades, with a loving intention of working at them, is of the most important significance. If our larger machine shops are visited, it will be seen that where apprentices are found, nearly all the places are filled by boys of foreign parents. I have made inquiries in several large cities, and I find that only a few shops are able to offer good opportunities for learning the machinist's trade, and that there are constantly a large number on the waiting lists. And that not over one-third or one-quarter of the acceptable apprentices are American boys. Also, that the American boys are the most unsatisfactory. By following up this surprising statement, I found that while the American boy has the natural mechanical ability, he lacks that reliability and vigor which comes from a less delicate home life. For example, the American mother would offer for the excuse of her son's tardiness or absence, the fact that Charlie was obliged to be out late attending to some social obligation, most unobjectionable in itself, and that he was so sleepy and tired that she had not the heart to call him to breakfast.

I mention this phase of our American life to show one reason why more of our boys are not learning trades and becoming leaders in a very promising field. It seems that the real solid inducements for learning a trade are being overshadowed by a few imaginary objections. Do not our boys feel that a mechanic must be deprived of too much time for social enjoyment and leisure, that some of the refinements of life must be given up, that the garb of a machinist and his surroundings are not to be desired,

and possibly that his associates will be inferior and undesirable! Add to these the objection of being unable to dress in "purple and fine linen" and keep the hands clean, and I think we have the principal reasons why American mechanics are growing proportionately fewer every year.

The Objections to Learning a Trade are not Real.

I submit that these objections are either imaginary and frivolous or that they exist with almost every other line of work with equal force. Take, for instance, the matter of leisure time for self-improvement and enjoyment. We must admit that many more genteel employments require much longer hours of business than those of the machinist, whose hours are constantly being reduced by law and custom, already, perhaps, to a doubtful extent. Or, take the matter of the refinements of life, which in the best sense are the most desirable elements of existence. We must not forget that so far as the employment of the mechanic is concerned, in itself it stands second to none; that the temptations in the shop are no greater than in the store or in the bank; that some of the most refined and excellent characters have been developed by earnest efforts in the shop, and by appropriating the opportunities for culture when outside of the shops; that the opportunity for the effect of uplifting and refining influence is not greater in any walk of life than it is in our machine shops and factories; that the opportunities for young men who are thorough machinists are likely to be better in the future than they have been in the past. This seems to me to be as certain as it is that we are living in an age of greater mechanical activity than any that has preceded. Every department of life requires more and more machinery, and American tools and machines are finding their way all over the world.

The Danger of the Real Machinist Becoming Extinct.

The boys with foreign parents are coming to the top, not because of their natural mechanical ability, but from their willingness to learn trades. In a few years these boys will stand ten to one American in our industries. You may say, What of it? I answer, I am not sounding an alarm against the foreign mechanic, because he is a *foreigner*, but because I believe that only by the *superior* native skill of Americans can our industrial supremacy

be held. We are dependent upon this, and for this reason we cannot allow our best boys to shun the shops and the trades for lawn tennis, golf links, foot-ball fields, and eventual clerkships.

What our Foreign Competitors are Doing.

Our foreign competitors are offering greater opportunities to their mechanics than they offered thirty years ago, and are endeavoring to do more for them to-day than we are. Practical trade schools are being established, and a wide-spread interest is aroused among thinking men of Europe in industrial education. It is not safe for us to think that our native mechanical aptness will always offset the value of better advantages and training, especially if foreigners select their brightest young men to go into their shops and our brightest boys are not induced to learn mechanical trades.

It seems to me that a little observation of what other nations are doing and how little we are doing for our mechanics will excite your attention and awaken your interest in this subject. Admitting what I believe is true, that our mechanical engineers, represented by the members of this Society, and that our schools for mechanical engineers, are not excelled, what can be of greater importance for continued excellence, success, and superiority in the industry of mechanics than a strictly American system of trade schools for machinists?

Robert W. Hunt, ex-president of this Society, has called attention to another phase of this subject which must not be overlooked, viz.:

If we will, we can, in due time, avert the great danger threatening from trade unions and make them a blessing, simply through the effect of a better schooling for our mechanics, a schooling that will influence the shop lives and the mode of thinking of our workmen.

Our machinists want a better chance. They deserve a better chance, and they will make good use of better skill and a broad technical education. The future of the engineering profession will also demand this. All engineers are dependent upon the shop and the machinist for the embodiment of their ideas. There is no body of men that can so readily and so effectually bring about this deserved boon of a chance to learn a trade and at the same time get an education as the members of this great Society.

The Difference between the Machinist and Engineer.

Having set forth above what I mean by the term "machinist," and what the significance of his position is, it seems to me that the fundamental idea upon which the proposition of the half-time school is based must be admitted, if the difference between the machinist and the engineer is recognized as *a difference of degree and not of kind.* There is no defined line of demarkation between the mechanic and engineer, and the same fundamental training may be made suitable for the successive grades of mechanics up to and including the mechanical engineer. The latter would have this schooling broadly supplemented by that of the engineering college.

The Prevailing Theory of Technical Education.

This idea that the difference between the machinist and the engineer is *a difference of degree and not of kind* is radically opposed to the prevailing theory of technical education. Professor Thurston in his discussion, it seems to me, brings out this theory clearly. The education of machinists, foremen, and mechanical engineers seems to him not one subject but three, and I gather from his remarks that he would advocate keeping the schools for each of these as distinct and separate as he claims the subjects are. This idea is also evident in the remarks of the Sibley College professors which he has quoted. Professor Shepard submits, "that the engineer who has served his time as a machinist has no advantage over the engineer who, with less knowledge of the machinist's trade, combines more knowledge of the other engineering trades," an idea radically at variance with the American idea of a machinist and of an engineer, and with the theory that machinists, properly selected, are the best material for making engineers. Professor Kimball does not believe it necessary for an engineer to actually do all the processes in a shop. Professor Ryan clearly marks the difference between the engineering trained young man and the man who has completed his trade as a machinist. He points out that it is the business of a technical education to train young men to get at the underlying principles, and the apprentice's training simply adds items of experience to his skill. Professor Jacobus, of Stevens' Institute, and William Barclay Parsons, Trustee of Columbia University, and others also emphasize this idea that the difference between the machinist and

engineer is *one of kind*, and that their education should be distinct and separate. This all tends to show that the modern idea of technical education is that it is provided for a different kind of a worker than the machinist, that the engineer does not need the machinist's experience, and that the machinist does not need to know the underlying principles. This is in deadly conflict with the theory upon which this paper is founded, that the logical development is from the machinist, by the steps of technical education, to the engineer. I would develop more theoretical knowledge and skill in machinists, and, in certain individuals of this class who show, by natural selection, a promise of higher things, develop in these few a difference of degree, until a well-rounded engineer is the result. The machinist needs as much of the underlying principles as he is capable of getting, and the engineer as much of machine-shop practice as is necessary to enable him to do the work himself. For if he cannot do it, it is not likely that he will know how to do it, or how other men should do it. If the foreman cannot take the place of the machinist, he lacks something as a foreman. If the mechanical engineer cannot take the place of the foreman and machinist, he cannot most effectively engineer the work.

This prevailing idea of technical education, that one class should be educated in a trade school for its work, and another class in a technical school for its work, and still another class in an engineering college for its work, is essentially British rather than American. The British principle of society is that of horizontal stratification, where each layer is well insulated from the others, so that all vertical circulation is impossible. While this British principle is generally applied to social life, it prevails equally in all industrial life in Europe.

To illustrate, let us for a moment view the productive forces as a lofty Temple of Industry. In the basement and on the lower floors are the laborers, where brawn is of more account than brain. On the upper floor the engineering is carried on. It is the British idea, and largely the idea of Continental Europe, that this Temple of Industry and Engineering is constructed without stairways, ladders, or any other means of vertical transportation of men. The various classes of men enter on their respective floors, and there remain. The engineers always enter by a high trestle, which is very high and very straight. This is the British picture, which seems to me to represent the view of some of our schoolmen.

These separate routes for various classes are clearly set forth by Dr. Thurston; their ways are all divided. He says: "For the child growing up toward the period of youth and the beginnings of a working life, manual training is as desirable as elementary instruction in the 'three r's.' To the young man seeking access to a working world a trade is imperatively needed, usually, and systematic instruction in the trade school is the ideal method of attaining skill and technical knowledge. To the youth seeing his way forward into a profession, no better route can be found, if naturally fitted for it, than through a well-organized school of engineering with its foundation solidly built upon general and scientific education, and with a strictly professional supplement in the higher departments of constructive work. Each of these departments is a separate and markedly different branch of preparation for a special line of work in life." He would have a school training which led in upon each floor of the Temple of Industry, whereas it is the central thought of this paper that the Temple of Industry is fully and amply provided with ladders and stairways, instead of insulated floors, and that large numbers of young men may enter and be trained and disciplined upon the lower floors without obstruction to moving upward when skill, ability, and fitness favor.

Elimination Should Begin at the Bottom.

The frugal New England father used to say: "My son, look out for the pennies and the dollars will look out for themselves." It seems to me almost as if we may say: "Look out for the American Machinist and the Mechanical Engineer will look out for himself." Among a large number of well-trained and well-educated machinists we are sure to get one or more expert engineers, men who will stand out against the sky as the few tall trees in a forest. These fittest ones are fed by the same sunlight, watered by the same showers, swept by the same storms, and have sprung from the same rocky soil; still, from some inborn energy, they stand exalted among their fellows. Thus are engineers born, and not made.

This is the true and natural order of life, and what I have emphasized in the original paper under the heading, "Education is complete at each stage," and I repeat that selection and elimination in the system for the education of machinists, foremen, and mechanical engineers should begin at the bottom and proceed up-

ward, rather than as is now the case with the technical school, beginning at the top and proceeding downward, dropping large numbers because they are failures.

When this fundamental principle is fully understood, educators will so modify the technical schools by having graded courses, without abandonment of the highest, best, and most scientific courses for those needing it, that the great needs of the many for training for mechanics will be met to a large extent, or, failing to make this necessary modification, new schools must be organized.

The Field of the Higher Engineering Schools.

There will always be a field for the higher engineering schools in connection with this scheme. The success of the technical school, which is everywhere recognized, and which I believe is largely responsible for our present industrial and mechanical supremacy, is due to its results in supplying the demand for scientific engineers. This demand will always be recognized, but it is a demand which is comparatively very small. Dr. Thurston places it in the ratio of one professional engineer to 10,000 trades workers. This is a ratio much greater than I assume in advocating the training of machinists in the half-time school as the best preliminary training for the engineer. This shows the very high idea of Dr. Thurston regarding the professional engineer, such as the engineering college aims to graduate, and emphasizes the fact that a great waste of effort and material is caused to produce one engineer, and that there are many failures or partial failures by those who have taken the highest course, without the preliminary training which I advocate, which has not, in the best manner, fitted a graduate for lower-grade work in life.

I do not mean to say that these men included in the term "waste material" are not of great benefit to mankind and use in the world, but they have not received the course of training best adapted to their capacities and work in life. Many of them have mechanical ability, and would fill with the greatest satisfaction the position of machinist or foreman, and perhaps eventually of superintendent. But a glance in the catalogues that publish the occupations of technical school graduates will show that those who have not succeeded in securing the positions of mechanical engineer are not filling the positions of machinists and foremen, but are going into some other line of occupation for which their course has not directly fitted them.

A mechanical engineering school has as its purpose education in a specialty, that of mechanical engineering, as much as a medical school has to educate in medicine, or a law school in law. We would not for a moment deny that the education received made a better worker and more efficient man in whatever occupation he undertook, than if he had not had it. So in a law school, even though the graduate might not become a lawyer, he would usually be more effective in whatever occupation he undertook for having had the training in law. But is not this method too expensive and wasteful? Can the technical schools afford to ignore these failures to fit their graduates for the position which they aim to fit them for, and at the same time ignore the enormous demand for more efficient workers below the grade of professional engineer?

The demand for engineers with more science and theory, which led to the founding of technical schools, has led, perhaps naturally enough, to an overpowering tendency to the abstruse and theoretical, and the only reason that shops have for their existence in most of these schools is as a sort of laboratory or manual-training department. They are not models of what a machine shop should be, and they do not teach what is known commercially as modern machine shop practice. Our technical schools are taught by scientists—by men who have devoted their lives to original scientific research. These men have solved many difficult scientific problems, to the great advancement of science and industry in this country, and it is therefore natural that the tendency of their management of the schools should be in this direction. But my conception of the technical school is one that shall aim to produce efficient skilled workers, in which some may be found who were born to be masters, and who should be trained to take a degree, not simply as masters of science, but masters in manufacturing and mechanical industry. We need a new degree: "B. I."—Bachelors of Industry. And, as the first logical step in this direction, the half-time school is proposed.

I have already distinctly emphasized that there is a field in the higher realm of scientific engineering which should foster and impart such knowledge, and that all professional engineers need not be the product of such a school system as the half-time school.

If some preferred to enter the profession directly through the engineering college, and to enter into competition with the few who, through their native fitness and energy, come up through the real and thorough experience of the school shop, the engi-

neering school would furnish the opportunity. It is claimed for the proposed system that the few who are sure to come up from the rank and file of the many, who would have elementary educational training superior to any other course, would eventually largely constitute the pupils of the higher engineering colleges, whose work would be consequently elevated, from the fact that the graduates from the half-time schools will be the choicest and the fittest, and would come to the engineering college in many ways much better fitted for professional work.

While there might possibly be room for all the technical schools there are to-day conducted on professional engineering lines if other schools were formed to lead up to them, at present the whole system is top-heavy. If two-thirds of the technical schools of to-day would lower their standards of entrance and adopt the principles such as are advocated for the half-time school, somewhat modified, of course, for their special requirements, they would be crowded with ambitious young men, and the need for technically trained workers would begin to be filled. The one-third remaining could devote their attention to a class of material selected for them from such schools and to those who desired to enter the profession on the air line.

In answer to the doubt that has been expressed regarding the possibility of fitting boys for the technical schools in the half-time school course of four years, attention is called to the hour plan prepared by Professor Alden, who, more than any other man, has had to do with the hour plan and course of study which has given the Worcester School its unique success in the combination of study and shop work. Professor Alden believes that such a course as his hour plan covers would be ample to fit the better scholars for the engineering and technical schools. And, in my opinion, only the better scholars ever should enter the engineering college.

The Manufacturing Engineer is Taking the Place of the Consulting Engineer.

Professor Hutton has forcibly called attention to an important change that has taken place in the condition of the professional engineer, which I think supports the underlying principles of this paper. He shows that the consulting engineer is being engaged by the seller instead of the buyer, and that the future engineer is to be a manufacturing engineer. This fact emphasizes the insep-

arable connection between the engineer of the future and the machine shop and machinist. Professor Hutton also shows that the present tendency of all manufacturing to centre under large heads or corporations is likely to do away entirely with the demand for the so-called professional consulting engineer and his office, corresponding to that of the lawyer. If educators are prompt to adjust the course of training to this imperative demand, great changes and great improvements will be made, and such schools as the half-time school will take an effective coöperative part in industrial education.

Not a Trade School Narrowly.

While there may have been in the past some misunderstanding of the difference between the manual-training school, the trade school, and the engineering college in the minds of some writers on the subjects, I think the difference is now well understood by all practical men. The trade school, so far as it exists, has for its object the teaching of a trade in a direct, practical way. These schools aim to take the place of the bygone apprentice system.

The proposed half-time school is not a trade school simply, it is much more; because, while it proposes to do more, and not less, in the trade work of the shops, it proposes to do much more than has ever been attempted in a trade school in the line of mental discipline and education. It is claimed that by judicious combination of shop work and studies, very favorable and excellent results may be expected in both directions of training—mental and manual. This high expectation is based largely upon the experience at the Worcester School, which combined the two successfully for twenty-eight years, under conditions less favorable than can be secured in the half-time school. The trade school, except in such schools as the Auchmuty School and a department of Pratt Institute, can hardly be called an American institution. The trade school exists in France in its purest form. It actually supplies the trades to some extent with trade workers. In England I have found nothing for the machinist worthy of the name of trade school. In Germany, while it is applied to many branches of manufacturing with some success, German mechanics are not developed in trade schools. In Switzerland, liberal expenditure of money is made for trade schools in certain branches —as, for instance, watchmaking—but so lacking in modern mechanical methods that it seems to me that the Switzerland trade

school will fail to meet the requirements of the competition of other nations. But it will be seen that all these nations are making efforts to train their trades workers, and they are improving in their attempts from year to year.

I have called attention thus briefly to existing trade schools to show the importance of a trade school in America of a different scope and character. Schools for American mechanics must be American in conception, organization, and administration. The American trade schools must teach more than a trade. Our skill is important and must be made superior to that of the workmen of any other land. Skill is not due alone to manual dexterity. Manual dexterity must be and can be supplemented by mental discipline and scientific education. When I say, "To be a thorough mechanic, which he ought to be before he can be a well-trained engineer, he must be able to do the work," I do not confine the term mechanic to one who has mere manual dexterity, as Professor Griffin seems to think, but what I refer to as a mechanic is the expression of the active mind trained and schooled to intelligent thinking, as well as of the trained eye and hand for expert doing, and perfect coöperation of the two is necessary to produce a skilled mechanic.

It is hoped that my foregoing remarks regarding the importance of the machinist and his business will make my position clear to those who think like Professor Shepard, U. S. N., who says in his discussion, "It appears to me that the author attaches undue importance to the machinist." On the contrary, I have a strong feeling that a great danger lies in attaching too little importance to the machinist. I think a mistake in the direction of this danger will be as fatal to the highest interests of American industry as any mistake that is likely to be made. Our mechanical engineers are not likely to degenerate, or to be found wanting when standing among the engineers of the world, but as yet there is no commensurate provision made for our machinists. A broad, high education of the American machinist is the best and surest possible support to the highest position and rank of our professional mechanical engineers. I am afraid that this truth is sometimes overlooked in our engineering colleges, and is not comprehended by professors. Scientifically educated men and professional educators can afford to be very broad in defining their work, and in dealing with those of us who are mechanics and manufacturers.

Real Work vs. "Exercises."

We hear considerable talk about the advantages of "exercises" over real shop work. There is an advantage in the exercise system in the ease and convenience to the school and the teachers, but a disadvantage to the student. It is said that the management of school shops, if allowed to put students into the shops on a par with mechanics, will work the boys too long upon one kind of work for the advantage of the productive interests of the shops. Why is this conclusion made?

I think it is not true that this will be so simply because it is possible. The instructors and management of school shops are selected for their ability and character. They are satisfactorily paid for the one high aim and purpose of teaching young men. They have no moneyed interest in the financial gain of the shops. No, there is no danger of interfering with the students' interests from this cause. About the only danger to be guarded by trustees in relation to the faithfulness of instructors is the danger arising from the tendency to choose the easiest way, to make the work of the instructor automatic, so that it will go with less and less effort. This tendency is really the great motive of introducing a fixed and uniform list of exercises.

One of the great advantages of real shop training for a young man is the development of a ready ability to *choose* between methods and to select wisely the best means. And no two cases are just alike. One method contracts and narrows the boy, and the other develops him into a man of resources. The instructors who advocate the exercise plan seem not to comprehend that shop instruction does not consist in cutting of chips and shavings only, but in giving experience in real manufacturing. This can be done if you will only put the boy into real manufacture of machinery, with suitable teachers, teachers who will guide just the right amount and let the boy go forward and upward. His development will be wonderful. Who would claim that a love letter produced by the use of the "Ready Letter Writer," with its phrases, was as good as a love letter written under the impulse of a full heart, where all form was perfect because of the eagerness to express the thought and adapt it to the emergency?

I hope our technical schools will not be inclined to repose upon the flowery bed of "exercise" as a substitute for the real thing. The best is none too good for a boy. If he does not know the

difference in school, he will when he gets out into the real working world, and he will finally bless the teachers who have been honest with him and taught him the real thing.

The real successful and commercial shop has been a great bugbear to the schoolman, who has feared, as Professor Sweet so aptly puts it, that the school will become a shop with school attachment. This fear should be done away with for the sake of progress.

The Necessity for the Best in School Shops.

The original paper treated of this to considerable length, but not fully, as that is impossible in such a paper. Briefly I wish to emphasize this important matter. A school shop must be a good shop with common-sense management, thoroughly practical, productive and commercial. The motto, "The best is none too good for a boy," must always be kept in sight. The teachers and instructors and lecturers in the school shop should be the best machinists, the best machine designers, the best engineers, and the best educated and cultured gentlemen that America affords. The school shops can afford to have the best, because such men will make it pay best, and turn out the best graduates. Then, as Mr. S. W. Baldwin has so truly said, "The fact that during the whole of the boy's four-year course he is living in a commercial atmosphere, is associated with men who appreciate and know the actual money value of an hour's time, will have an effect upon the boy's future hard to estimate." It is surprising to one who has not had experience with students in a commercial shop, how quickly they become competent to do good, reliable work.

The Shop Lecture Room.

The shop lecture room is a new and important feature. It will yield as great results in science and in culture as any lecture hall in Harvard, Yale, or Columbia, provided you have equally good teachers.

The opportunities and surroundings are decidedly in favor of the shop lecture room, because time to teach is when the pupil wants and needs the instruction. Put a boy in a good school machine shop, load him well with mechanical responsibilities, and if he is born for the business, he will be fired with the ambition to progress and to succeed, and consequently will constantly run up against difficulties, mechanical, physical, electrical, chemical,

etc., all calling for the most scientific instruction. He is in practical need of instruction at all points, and hence his eagerness is like thirst, and he absorbs like a dry sponge. What conditions can so well meet the ideas of the true teacher as this! Furthermore, effective shop teaching need not be confined to mechanical things. Any man who has had a real and broad shop experience knows what an all-pervading influence the superior man has over his shop-mates, and how the influence of the superior officer is felt whenever the cultured man comes into touch at all with the lives of the men.

Coöperation with the Public Schools.

Admiral Melville calls attention to the improvements needed in our common schools for the benefit of mechanics. We have waited so long for these improvements in behalf of the industrial classes that it is not to be expected that the school boards of our cities will establish half-time schools, but it is not unreasonable to expect that if some success can be obtained through such a private enterprise as is proposed by the half-time school, that it will have a most desirable influence upon our public educators. When they see what good can be accomplished by private corporations, they will gladly work to introduce such new methods into the public schools, and when this time comes the taxpayers will be glad to favor new methods.

I find that the paper did not make clear to every reader that the proposed shops of the half-time school are entirely independent of all school boards and all other control, except that of the private corporation, organized and chartered solely to conduct the shops upon a commercial basis for the education of young men, and that this shop constitutes only one-half of the half-time school. The other half of the half-time school is to be conducted and controlled by the public school board similar to the high school. It is believed that any school board will favor and coöperate in their part of the half-time school, because it involves no serious change in the present high school, except to slightly modify the course of study, and the hour plan, so as to accommodate this class of boys, who elect to spend half of their time each week in the school shops. The school board cannot object on the ground of expense, because, as regards both room and teaching force, there is much in favor of the half-time system proposed. By the alternating of

pupils from the shop to the schoolroom, double the number of pupils can be accommodated. I find that advanced educators are heartily in sympathy with such an adjustment, and where it is understood, have unanimously admitted its practicability. Furthermore, a general public feeling is developing that we are having too much *book* and too little *work* in our school system.

Control of School Shop by Private Corporation.

There have been numerous criticisms upon the proposed half-time school, which I think are honestly and naturally made along the line of difficulties which it is thought may arise from the objections of manufacturers, and from the misunderstandings of taxpayers.

I have mentioned that these were the only sources of real difficulty in the way of successful commercial school shops being assumed by the public schools, and, when I have referred to the coöperation of the public schools, it will be noted that I do not advocate the assumption of the school shop by the public school board at present. Whatever the needs of a community for industrial training, and however great good would result from such training, just so sure as its introduction is attempted by the public schools or by untaxed educational institutions and schools aided by the government, just so sure are we to be met with objections from taxpayers and competing manufacturers. Hence this is the strongest argument for conducting and controlling that portion of industrial training which is given in the school shops by a private corporation. Such an important departure as that proposed by the half-time school must be controlled by a small board of managers who see clearly, as one man, what should be attempted, and which can provide the necessary methods for carrying out a continuous, persistent policy. Such a board of trustees would be beyond suspicion of personal interest and beyond the danger of being diverted from a sound policy. The advantages of such private corporation, and also the necessity of such a policy, apply with equal force to the question of the workability and the economical financial conduct of the commercial element of the school shop. Perhaps eventually, after a half-time school has been successfully carried on by a private corporation, which cannot be dictated to or hindered by any selfish or political interest or whim, it will then be a most promising time to introduce the system into our public schools.

Long Vacations.

In reply to the objection to my proposition to save to the student much that is now lost, or worse than lost, by long vacations, on the ground that it is impractical, I wish to call attention to the fact of the great success of summer or vacation schools throughout this country for the past ten years. This is the best and strongest evidence that the old, long vacations are not necessary or desirable, if advantage is properly taken of the virtue of change of work, rather than entire cessation of work. Another strong evidence in the same direction comes from the fact that progressive men, such as Dr. Harper, adopt continuous teaching with success, as, for example, at the University of Chicago.

Financial Aspect.

In regard to the criticism and lack of faith in making such a shop as I advocate financially successful, I simply refer to the history of the twenty-eight years' experience at the Worcester Polytechnic, published in the original paper, which proves that point beyond any reasonable doubt. I do not, however, insist that financial success is necessary to the scheme any more than it is in any other system of education; I simply submit that it is practicable and possible, and with the right conduct the tendency will necessarily be in this direction.

The Next Advance in Education Must Come from without the Schools.

President Tucker recently said that "the next advance in education must come from without the schools, and not from within the schools." This is so true and so important that the following question is a natural one. If the needed advances in mechanical or industrial education are to come from without the schools, where can we look with greater hope than to this Society? If American youths are seeking training they cannot obtain, if the profession is suffering for trained skill in machinists and foremen, and if ninety out of every one hundred who are learning mechanical trades are foreigners of inferior ability, is it unreasonable to expect that a remedy may come from among the nineteen hundred members of this Society? If we have it not at heart to solve this problem, where can we look for hope?

I submit that no time or condition since the dawn of educational history has offered such an opportunity for important results as the present offers to those who can make educational provision for the needed training of the American mechanical workman. Upon this training depends very largely our future position among the industrial nations. This is the hopeful remedy for the most grievous class distinctions and strikes at the foundation cause of all labor difficulties.

DISCUSSION.

Prof. C. H. Benjamin.—I have been much interested in the papers by Mr. Higgins on the subject of technical education, and am in many ways in sympathy with what he says.

I am not, however, ready to admit that the modern technical school of the first class is on too high a plane for the best interests of the community. I do not know how it may be in the Eastern schools, but in the portion of the country where I reside we have few "failures" among our graduates, and at the present time the demand for just such young men far exceeds the supply. We aim to produce not skilled workers, but skilled *thinkers*, and with all deference to Mr. Higgins's classification, I must consider the latter superior to the former.

I may or may not be a scientist, but I was once a machinist, and am in sympathy with practical training as a means to an end. I believe a school shop should be as much like a real shop as is possible, in methods, in management, and in discipline. But I do not believe it should be a commercial shop and make things to sell, and I do not believe that the manual labor should be allowed to encroach on the scientific training. We should remember that we are not training the hands for themselves, but that we are, or ought to be, training the mind, through ears and eyes and hands.

I know from experience that the most of machine labor is drudgery, and the machinist is not and cannot be on the same plane as the engineer as long as he remains a machinist.

Now this is one reason why our boys are not learning trades, and another reason is because the trades unions in most cases oppose, and even persecute, apprentices.

The graduate of any kind of school shop will usually find life

a burden when he enters a real shop unless he bends to the unions.

Notwithstanding all this I do believe that there is a place for some such school as Mr. Higgins advocates, a school for the boy who is destined to be a mechanic, that he may be a better mechanic, and possibly become a foreman or superintendent.

I am still in doubt about the commercial side of it especially in dull times, and can see no way to make such schools secure unless heavily endowed. As a part of the public school system a school of this kind would be too heavy a burden on the taxpayers, but if wealthy men can be induced to endow and manage schools which shall give to mechanics a thorough elementary education, and at the same time systematic shop training, the results will give a good interest on the investment.

Mr. John McGeorge.—This is a subject in which I am very deeply interested in two ways; first, as a father of boys growing up; second, as an employer of other boys coming from other homes. The first thought that comes to me through the reading of this paper is to commence with the last of the paper, this last paragraph. I think that we ourselves are very largely to blame for the condition of affairs at present existing. We have not put the position of the machinist on the high plane on which it ought to be put. We have rather looked down on the machinist as not being the equal of the draughtsman or the superintendent or the foreman. I remember in my young days being a candidate for the Whitworth scholarships. I had no theoretical training such as the boys get in these days. I was at work at fourteen, not going to half-time school, but working from 6 o'clock in the morning until 6 o'clock at night, and then going to evening school. During that time I competed for those scholarships for three years. I partly succeeded at last, but it was after a hard struggle. Whitworth's idea in establishing those scholarships was to make the chance of the apprentice who worked chiefly with his hands equal to that of the boy who was trained in the technical schools; but it was not so, not by a very long way. The students of technical schools had four times the advantage of the boy who worked with his hands. The first year I competed, the first thing that I noticed was that where the student only got two hours' examination in a certain branch of trade, the working boy had to take an eight-hour examination and the two only counted

equal. Again, in comparing experiences with others coming from technical schools, I went over the relative marks to be obtained, and I found that Sir Joseph's intentions were completely subverted by those who had laid down the rules of the competition, giving the advantage entirely to the side of those who were going through the schools. Now there is where we are making our mistake. I am feeling it to-day. I have three boys. One has gone through the shops and got his schooling as I did, in his evenings' time. He now is the general manager of a very successful electric manufactory at twenty-five. The second one went through the draughting-room and is a very successful draughtsman. The third one is going through the shops now. But there is where I see the difference; he does not feel that he is the equal of the other two. He always feels that he is looked down upon because he has worked actually in the shops. It is useless to remind him that the first one went through the shops entirely and is now in a successful position. But there is the feeling of the American youth—and I am sorry to say that feeling is encouraged by people who are always pointing up—to get up higher. I am reminded somewhat in connection with this of a bit I read the other day, the comment of an old miner. He said that he had been thinking a good deal about low-grade ores. The prospectors were constantly going about seeking for rich strikes, seeking for high-grade ores that would bring in fortunes in a day, while the Chinamen and other steady people would go and take their leavings and work out not merely comfortable livings, but fortunes, through grinding steadily at the low-grade ores. It seems to me it is just like that in our schools; our students do not know what the low-grade ores are worth. They are encouraged to go on to the high-grade ores, high positions, positions of superintendent, just as high as they can go, and with the big salaries. They do not care to go on with moderate salaries day after day, with steady work as machinists, and I think it depends on this society to discourage that idea that the machinist, the skilled machinist, is not worthy of the highest praise. I well remember Mr. Gladstone's remarks, addressing some workingmen, when he tried to point out this very thing to them, showing that they were doing as much for the world, doing as much for themselves, and doing as much in every way as could be expected of them by working to the best of their ability at the trade they were

in. Let me just tell you another feature of that same thing. I noticed in Mr. Higgins's remarks a sentence about trying to put the entire class of students to a plane for which they are not fitted. That was not the language, but that is what it meant. Are we not making a mistake there? We take large classes of students and give them all the same treatment, and try to raise them to a mountain height that they cannot reach. When we do that we simply take a lot of men who never will be successful as leaders, who never will be real engineers, and spoil them for positions which they could fill and fill well. Should we not encourage the raising of the standards of admission to these classes, and do a good deal more weeding out? I have in my mind now some young men of my acquaintance who have gone through high school and are about going to technical schools. They do not recognize their limitations. They never, so far as human foresight can see, will make the men they suppose they will. If they would stick steadily to some other so-called lower forms of work—a term I do not acknowledge—but to some other class of work, there they can make a success, leaving the apparently higher positions for others who can fill them, and this I think we can encourage by raising the standard of admission to those higher classes. I do not know whether I have made my meaning clear, but the sum and substance of the whole thing is: let the American youth forego the gambling spirit—I can only put it on that score—for wishing to make fortunes in a day, in other words, wishing to get something for nothing, to make rich strikes in place of steady work.

Mr. George I. Rockwood.—The first paper by Mr. Higgins I have read with some care, but this second paper I have not had an opportunity to examine so thoroughly, and may not, therefore, do him full justice. In so far as Mr. Higgins's ideas relate to the training of foremen and machinists, and of superintendents possibly, I think I am heartily in sympathy with him, without being able to defend my sympathy on precisely the same logical grounds that he puts forward. I must say, however, that Mr. Higgins's paper is not to be treated in any small or Philistine spirit. There can be no man in this country or in the world who has any greater claim upon our attention in regard to this subject or any greater claim to know whereof he speaks than Mr. Higgins. He, himself, is a successful manufacturer. He is also a successful instructor of youth—a rare

combination in one man; and he is not a visionary; he is intensely practical. If this paper is open to any objection, it seems to me it would be open to the objection of being too practical. That would be a matter of opinion, however. The paper itself must be conceded to be of great value, possibly to mark an epoch in industrial education. Evidently the scheme is worked out to its farthest limits, and with the genius of Professor Alden to assist him, it may be true that no valid objections can be maintained against his arguments. I, however, wish to speak of the present position of the consulting engineer in the business world, being incited thereto by the apparent attitude of the paper with regard to this position, and of the automatic way he is to be produced, if Mr. Higgins's reasoning is correct.

Every one has theories of education, and theories which, for the most part, are different from those of everybody else. How rare it is to have two educators or two engineers agree upon the details of a process of education! In regard to the education of the consulting engineer, I feel strongly myself that the engineer of the future is not, for one thing, to be submerged in great corporations. I think it is a fair question, an open question, whether these great corporations themselves are going to last, although perhaps that may prove to be the ultimate method of business. Nevertheless, it seems to me reasonable to believe that the consulting engineer as a species is not to become extinct in consequence of these corporations. There are too many places and positions and "jobs" which he can do in an independent capacity, which he cannot do if in the employ of a corporation. Nearly all street-railway work, nearly all power-plant work, nearly all mill engineering and mill architecture, nearly all "civil engineering," must be done by an independent engineer or firm of engineers; and these requirements alone will always, it seems to me, sustain the consulting engineer in an independent position, free of corporations; so that the manufacturing engineer is not really taking the place of the consulting engineer. I do not know that I ever heard of a consulting mechanical engineer who did nothing but design machines; perhaps there are such men, but my conception of the consulting mechanical engineer is that he deals, for the most part, in broad questions of policy and administration, and of the arrangement and also detail of machinery and buildings.

How is such an engineer to be produced? Is he not the true

product of our technical schools as they are now organized? It seems to me he is. But the next development in technical schools, especially if Mr. Higgins succeeds in establishing his half-time school, must be to place the technical schools on a *purely* professional basis. There has been a strong feeling current, as you are all aware, that a technical or scientific education can take the place of a liberal education in producing a properly educated man—not a professional man, but a man who is an end in himself, a man who is a satisfaction to the community in which he lives, a man who in his personality completes, so far as it is possible, the end of life. The question is whether scientific training alone will ever be likely to produce such men. I believe it is not enough. I believe that the time will come when all American youths will feel somewhat ashamed of the fact if they have not had at least a full collegiate training; and such as are fitted for professional work will then pursue a purely professional course on top of their collegiate training, with possibly an interim of practical work, possibly not, according to their individual absorptive powers. There is a limit to the cramming process. It must frequently be interspersed with a year or two of practical labor. It is a hobby with me to think that if every graduate of a college, who wanted to be, for instance, a theological student, would go out and work in a bank or in a machine shop for three or four years and then take his course in the theological seminary, he would become at once, on graduation, a minister, instead of still requiring a long period of incubation before he is really fit for such work.

Certainly, the end and aim of life is not simply to equip professional men; it is not simply to equip people with the power to "do business;" it is not *simply* to enable people to earn a living. None of these is the most serious aim of education. "It is the object of education to render available all the powers of mind and body which a man may possess, and to bring each to coöperate with the others with rapidity and certainty." That is my quoted definition of the object of education. Now, that ideal must not be departed from in the higher ranks of education, and I am persuaded that it will not ultimately be departed from. We have at present a very strong tendency toward the practical, and it is a legitimate tendency; but it is a makeshift, not the ultimate thing; and while I sincerely hope that Mr. Higgins's school may be established, and that it is a solution of a

pressing problem, I think that it is carried to an extreme when it is proposed thus to produce consulting engineers. I doubt if engineers can ever be produced by natural selection. There will always be miserable failures, and there will always be those who are inert. That is the great trouble with people nowadays. Boys have not distinct individuality or a distinct "bent," and are only to be coaxed into doing this thing or that thing in the hope of making money. Whether you can, by any means of education, instil ambition and instil hope and instil purpose is a question; but professional schools to-day would produce few failures indeed if all men had those three characteristics.

I take it, however, that there is a real demand and place for such a school as Mr. Higgins advocates. It would be both democratic and truly benevolent to provide them for the great body of machinists' and other artisans' sons as they exist in America to-day. Perhaps, too, they will always be needed. But it is when Mr. Higgins raises his plan for a "half-time" school into a general system for the education of the engineer, in the largest sense of that term, that I can find it in my heart to offer any criticism at all of his able and persuasive plea for the establishment of these schools.

Mr. Paul M. Chamberlain.—I have been very much interested in these papers of Professor Higgins, and whether or not his ideal is ever accomplished, I believe that technical education will be benefited by the stirring up he has given it, that the technical schools will be improved by the suggestions that have been brought out at this time, and that certain of the objects that Professor Higgins has in view will be accomplished. It seems to me that there is some misconception regarding the differences of capacity required for a good mechanic and a good engineer. I believe in general that the man who, with a careful training, fails to make a good engineer would not have made a good mechanic. The requirements for both are very much the same so far as natural faculty and perseverance are concerned. In the technical schools there are many problems yet to solve in regard to teaching that, when solved, will be advantageous to the engineer. There is a lack of coördination that is partly due, I presume, to the youthfulness of the schools, and partly to the fact that we have not the proper talent to draw from for teachers. There is not the financial incentive for our engineers or mechanics to engage in teaching that there is in commercial-

etc., all calling for the most scientific instruction. He is in practical need of instruction at all points, and hence his eagerness is like thirst, and he absorbs like a dry sponge. What conditions can so well meet the ideas of the true teacher as this! Furthermore, effective shop teaching need not be confined to mechanical things. Any man who has had a real and broad shop experience knows what an all-pervading influence the superior man has over his shop-mates, and how the influence of the superior officer is felt whenever the cultured man comes into touch at all with the lives of the men.

Coöperation with the Public Schools.

Admiral Melville calls attention to the improvements needed in our common schools for the benefit of mechanics. We have waited so long for these improvements in behalf of the industrial classes that it is not to be expected that the school boards of our cities will establish half-time schools, but it is not unreasonable to expect that if some success can be obtained through such a private enterprise as is proposed by the half-time school, that it will have a most desirable influence upon our public educators. When they see what good can be accomplished by private corporations, they will gladly work to introduce such new methods into the public schools, and when this time comes the taxpayers will be glad to favor new methods.

I find that the paper did not make clear to every reader that the proposed shops of the half-time school are entirely independent of all school boards and all other control, except that of the private corporation, organized and chartered solely to conduct the shops upon a commercial basis for the education of young men, and that this shop constitutes only one-half of the half-time school. The other half of the half-time school is to be conducted and controlled by the public school board similar to the high school. It is believed that any school board will favor and coöperate in their part of the half-time school, because it involves no serious change in the present high school, except to slightly modify the course of study, and the hour plan, so as to accommodate this class of boys, who elect to spend half of their time each week in the school shops. The school board cannot object on the ground of expense, because, as regards both room and teaching force, there is much in favor of the half-time system proposed. By the alternating of

from all walks in life; they are apprentice boys and journeymen, superintendents and draughtsmen; and of 900 students who thus come to us, many are occupying positions of trust with lucrative incomes, who come for special work. One man who has not had the work on the milling machine with which he is anxious to become acquainted comes and expects to get the best instruction possible in milling-machine work. Another one perhaps is after lathe work; others are there for tool-tempering, tool-dressing, foundry work, mechanics, pneumatics, drawing, electrical or mechanical laboratory testing. The effect of this on the instructors, who are also with the undergraduates of our regular engineering course, is to stimulate them to such endeavor as is necessary to bring themselves to the very highest proficiency they are capable of reaching. The constant contact of the teacher with students who know much less is apt to cause him to let slip away that which he has known, and keep that sort of knowledge which he finds necessary to impart to those knowing a great deal less. If by some method such as the one that I have just mentioned, but which I understand is impracticable in all cases, the instructor is brought daily, or at least frequently, in contact with journeymen and engineers, who are nearly as skilled in some, and in many respects more skilled than he is, the standard of the undergraduate student could be raised to a remarkable extent. The sifting process, or rather the reverse, that Professor Higgins mentioned, we find possible in students who come to us for this fragmental work in the evening schools; but those who are ambitious, and lack the fundamental training, find that it is extremely difficult, and likely to take them until old age before they accomplish the entire ground which they wish to cover. Many of these shift into the regular engineering course, and, as might be expected, among them are some of the best material that we have.

Mr. E. B. Johnston.—I would like to ask Mr. Higgins if it is implied that one-half of this schooling should be given in actual shop practice, and the other half in the school? If that is the fact, I think the sooner the society takes some cognizance of it the better. Two or three days ago a young man came to me and applied for a position as apprentice. I saw some of his drawing. It was crude, and in a way very amateurish. I gave him some of our work as a sample, and told him to take it and see what he could do. He returned this morning and showed

Long Vacations.

In reply to the objection to my proposition to save to the student much that is now lost, or worse than lost, by long vacations, on the ground that it is impractical, I wish to call attention to the fact of the great success of summer or vacation schools throughout this country for the past ten years. This is the best and strongest evidence that the old long vacations are not necessary or desirable, if advantage is properly taken of the virtue of change of work, rather than entire cessation of work. Another strong evidence in the same direction comes from the fact that progressive men, such as Dr. Harper, adopt continuous teaching with success, as, for example, at the University of Chicago.

Financial Aspect.

In regard to the criticism and lack of faith in making such a shop as I advocate financially successful, I simply refer to the history of the twenty-eight years' experience at the Worcester Polytechnic, published in the original paper, which proves that point beyond any reasonable doubt. I do not, however, insist that financial success is necessary to the scheme any more than it is in any other system of education; I simply submit that it is practicable and possible, and with the right conduct the tendency will necessarily be in this direction.

The Next Advance in Education Must Come from without the Schools.

President Tucker recently said that "the next advance in education must come from without the schools, and not from within the schools." This is so true and so important that the following question is a natural one. If the needed advances in mechanical or industrial education are to come from without the schools, where can we look with greater hope than to this Society? If American youths are seeking training they cannot obtain, if the profession is suffering for trained skill in machinists and foremen, and if ninety out of every one hundred who are learning mechanical trades are foreigners of inferior ability, is it unreasonable to expect that a remedy may come from among the nineteen hundred members of this Society? If we have it not at heart to solve this problem, where can we look for hope?

cord. He may make mistakes, or even break a machine, but he does it with good intent, and nine times out of ten such a boy will make a good workman for you. When a boy comes to you from a technical school he knows how to use tools. He is precise in the work which they have given him, and all that sort of thing, but he may not have any more ability than a boy that comes in without all these advantages. How many boys to-day that have undoubted talent have fathers who can give them that technical course? In some schools a boy must have a high-school education before be can enter. There are many men to-day who might have made their mark if they had been given such chances as the half-time school system would afford.

Mr. William Kent.—I am afraid that all that the members of this Society can do for Mr. Higgins is to give him our heartfelt sympathy and say, We are with you; go ahead. We cannot start this school for him, and the technical schools existing are not going to change their methods. They are about all right for turning out the kind of men that are coming to them. Columbia is not going to change its course of mechanical engineering very much, or Cornell, or Worcester. But Professor Higgins has shown the need for a new kind of school capable of filling a larger domain than the technical schools now have. I think we will all give him our sympathy and encouragement.

What is wanted is several millionaires with the idea that the thing for them to do with their money is to start such a school as Mr. Higgins wants and put him at the head of it, and I hope some millionaire who is thinking, "What shall I do with my money before I die?" will come to Professor Higgins and say, "Here you are; start this school right away." I think, if this school is once started, the idea will grow just as fast as the idea of a technical education has grown within the last twenty years, or the idea of manual-training schools. About twenty years ago I visited the then new manual-training school in St. Louis and saw Professor Woodward, who took me into the blacksmith shop. There I saw twenty students working at the blacksmith's forges. I said, "There is a revolution in the technical education of this country." You have seen how that idea, started in St. Louis, has grown, and I hope Professor Higgins will soon get his millionaire, who will put this idea of a new kind of school into practical execution.

Mr. William Lodge.—I have read Professor Higgins's paper on

a burden when he enters a real shop unless he bends to the unions.

Notwithstanding all this I do believe that there is a place for some such school as Mr. Higgins advocates, a school for the boy who is destined to be a mechanic, that he may be a better mechanic, and possibly become a foreman or superintendent.

I am still in doubt about the commercial side of it, especially in dull times, and can see no way to make such schools secure unless heavily endowed. As a part of the public school system a school of this kind would be too heavy a burden on the tax-payers, but if wealthy men can be induced to endow and manage schools which shall give to mechanics a thorough elementary education, and at the same time systematic shop training, the results will give a good interest on the investment.

Mr. John McGeorge.—This is a subject in which I am very deeply interested in two ways; first, as a father of boys growing up; second, as an employer of other boys coming from other homes. The first thought that comes to me through the reading of this paper is to commence with the last of the paper, this last paragraph. I think that we ourselves are very largely to blame for the condition of affairs at present existing. We have not put the position of the machinist on the high plane on which it ought to be put. We have rather looked down on the machinist as not being the equal of the draughtsman or the superintendent or the foreman. I remember in my young days being a candidate for the Whitworth scholarships. I had no theoretical training such as the boys get in these days. I was at work at fourteen, not going to half-time school, but working from 6 o'clock in the morning until 6 o'clock at night, and then going to evening school. During that time I competed for those scholarships for three years. I partly succeeded at last, but it was after a hard struggle. Whitworth's idea in establishing those scholarships was to make the chance of the apprentice who worked chiefly with his hands equal to that of the boy who was trained in the technical schools; but it was not so, not by a very long way. The students of technical schools had four times the advantage of the boy who worked with his hands. The first year I competed, the first thing that I noticed was that where the student only got two hours' examination in a certain branch of trade, the working boy had to take an eight-hour examination, and the two only counted

students under Professor Higgins. I can bear testimony, and do it with pleasure, to his efficient work. It seems to me that the points he brings out are very valuable for one reason certainly, in that it enables the educator to determine, before the student comes to the technical school, something of the bent of the student's mind.

All of us who have had the benefit of a technical education know that a certain portion of our time was spent in determining in our own minds, and in the minds of our instructors, the special line that we should follow. Now, if this half time school will enable a boy taking the course to determine at the close whether he shall take up the line of studies in the technical school that will fit him for an engineer, designer, inventor, or metal-worker, he will be able to go forward with that work and make out of it at least double what he could make if he came without previous training.

The only question is whether it is a practical method of covering the point that Professor Higgins wishes to cover. I think one of the strongest points Professor Higgins makes in his paper (although I confess to having given the first paper very little study—I have read the last one) is that of bringing the student early in life in contact with the commercial side of the problem. I believe to-day that the boy who learns merely to handle tools (while that is an advantage), if he has nothing to show him the necessity of doing work quickly and economically, as he would have to do it in competition, has had an incomplete training.

It seems to me, therefore, that we, as a society and as individuals, can well afford not only to wish Professor Higgins Godspeed, as has been done to-night, and to echo the hope that some millionaire will find it in his heart to start this work forward, but to put our shoulders to the wheel. Dr. Parkhurst once said in Chicago, in speaking of the question of reform: "Gentlemen of Chicago, you will never see reform in Chicago until you take your coats off and prepare to keep them off." We shall never see this work carried through until we, as members of the society, not only hope that millionaires will come forward with the money, but, if necessary, take our coats off and keep them off in the interests of this work.

Prof. W. T. Magruder.—Mr. President, I desire to thank Professor Higgins for his exposition of what he understands as a ma-

in. Let me just tell you another feature of that same thing. I noticed in Mr. Higgins's remarks a sentence about trying to put the entire class of students to a plane for which they are not fitted. That was not the language, but that is what it meant. Are we not making a mistake there? We take large classes of students and give them all the same treatment, and try to raise them to a mountain height that they cannot reach. When we do that we simply take a lot of men who never will be successful as leaders, who never will be real engineers, and spoil them for positions which they could fill, and fill well. Should we not encourage the raising of the standards of admission to these classes, and do a good deal more weeding out? I have in my mind now some young men of my acquaintance who have gone through high school and are about going to technical schools. They do not recognize their limitations. They never, so far as human foresight can see, will make the men they suppose they will. If they would stick steadily to some other so-called lower forms of work—a term I do not acknowledge—but to some other class of work, there they can make a success; leaving the apparently higher positions for others who can fill them, and this I think we can encourage by raising the standard of admission to those higher classes. I do not know whether I have made my meaning clear, but the sum and substance of the whole thing is: let the American youth forego the gambling spirit—I can only put it on that score—for wishing to make fortunes in a day, in other words, wishing to get something for nothing, to make rich strikes in place of steady work.

Mr. George I. Rockwood.—The first paper by Mr. Higgins I have read with some care, but this second paper I have not had an opportunity to examine so thoroughly, and may not, therefore, do him full justice. In so far as Mr. Higgins's ideas relate to the training of foremen and machinists, and of superintendents possibly, I think I am heartily in sympathy with him, without being able to defend my sympathy on precisely the same logical grounds that he puts forward. I must say, however, that Mr. Higgins's paper is not to be treated in any small or Philistine spirit. There can be no man in this country or in the world who has any greater claim upon our attention in regard to this subject or any greater claim to know whereof he speaks than Mr. Higgins. He, himself, is a successful manufacturer. He is also a successful instructor of youth—a rare

engineer. Take Professor Higgins's illustration as to this Temple of Industry. The engineering college undergraduate does not propose to get to the top floor by going in "on the horizontal." He goes in on the ground floor off the broad highway of public education. The fellow is cautious. He proposes to go to the top of the house by one of the many stairways leading upwards, as his ambition tells him that his office in life is on one of the upper floors. He goes up two or three steps at a time rather than spend time going into every closet and corner of each and every one of the rooms on each and every floor.

Answering my friend, Mr. Lodge, I would state that I am not familiar with the technical college graduate who is very glad to get three to six dollars a week, and think that he is confounding the graduate of the engineering college and the graduate of the manual-training school. Taking last year's class of the institution with which I am connected, I would say that some of them are getting from thirty to forty cents an hour. I know that we have to pay at our engineering college fifteen to twenty cents an hour and upwards to students who are able to do different classes of mechanical work, and we cannot get them for any less. Again, there seems to be a misunderstanding on the part of many as to the ability of the technical-school graduates to obtain and to keep positions. They do it in some way or other. Several of our graduates who have been out only two or three years are getting from twelve to fifteen hundred dollars per annum. Somebody must surely want them. Employers are surely not paying good money for poor service and yet asking for more of the same kind.

Many of the undergraduates of the engineering schools have had experience in the shops, not for the term of an apprenticeship in all cases, but for terms of two or three months at a time during the summer. Only 10 per cent. of our graduating class in mechanical engineering this year but have had from three to twelve months, if not more, of experience in commercial shops over and above what they got in our school shops.

Half-time schools may come, and I trust that they will, but you must not expect the engineering colleges to turn themselves into half-time schools.

It simply rests with you gentlemen of Cleveland, you gentlemen of Cincinnati, we of Columbus, to look into this matter. If you believe in this half-time school idea; if you employers

need this kind of mechanic—not the plain, simple machine tender, but if you need more high-priced, thoroughgoing, practical, educated mechanics—then you must put your own shoulders to the wheel and see that that kind of school is inaugurated. The State in this public-school system of education looks not for the training of its youth solely in some one line of industry: it looks to the broader training, and of making boys into the best citizens. It is necessary and desirable to teach them United States history, civics, and things of that kind pertaining to civil government and to economics in State grammar schools, State high schools, State universities; and that being the case, it is for you manufacturers, who need these men, to push the idea to financial possibility and to educational success. Here in Cincinnati I would urge you to contribute not only tools of your own manufacture, but your time and money as well. Use the Cincinnati Technical School in this city, and use it night and day. Make a start to train up these men, if you want and need them, and you will find that the boards of education of this State will meet you more than half-way.

Mr. E. B. Johnston.—Mr. Magruder in speaking of the medical profession forgot to speak of surgery, which is the most necessary adjunct to that profession. Surely the doctor who understands surgery is better able to take care of his patients in a case of emergency than one who simply understands medicine and nursing. To-day an artist must understand everything from the bony structure to the position of every muscle. What percentage of your young men were taking from two to twelve months' course in the shops?

Professor Magruder.—I say that this year only ten per cent. have not taken it.

Mr. Johnston.—Then you acknowledge the efficiency of such practice?

Professor Magruder.—Undoubtedly. Get all you can of it, but do not spend all the days of your life getting it in order to be an engineer when you are an old man.

Mr. Johnston.—How long would it take the technical school capacity of to-day to equip the modern machine shops of this country with graduates sufficiently equipped with knowledge and shop practice to fill those positions? As soon as you do that you will never have any more trouble about the labor question. Any man is proud of his profession if he is anything

of a man. As I understand it, Mr. Higgins's idea is to take those who have not got that chance, to take those boys and give them that one-half day in the shop practice and the other half in the collegiate course, and then let them take the technical school.

Prof. F. L. Emory.—It seems to me that this question is being confounded with the question which has been pending in the American Society for the Promotion of Engineering Education, which has been wrestling with the problem ever since its inauguration in 1893. There the question seems to be what preparation shall be necessary for admission to a course in mechanical engineering? What shall be the extent to which that course shall be carried? What shall be the product? We have a number of distinct classes of schools, many of which are trying to turn out one grade better product than the stock will permit. One cannot very well discuss the whole question without having some points a little better defined, because it is merely a matter of individual opinion. If we can say just exactly what the training shall be, just how much training the boy has before he enters, just what we want to produce, then we can obtain that product.

But, on the other hand, I understand that this paper is a plea for an absolutely new kind of school. In that connection I heartily agree, reserving more or less for individuality and the personal equation. I had a little experience in connection with reformatory work along the trade-school line. Some years ago it was my pleasure to establish a trade school in a reformatory. There were about 800 men. They were of such stock as you might expect in such an institution. Some of those men did not want to learn. I put a certain young man in the trade school, after some examination of his physical and mental condition. I concluded that he would make a very good bricklayer. He differed with me. The result was that he served some days in solitary confinement, but he came out willing to work. He was on the half-day principle. We put him in the trade school half a day, in the afternoon, and taught him all the principles of bricklaying. He built piers and walls and made cuts of the brick. We tried to put into him all the technicalities of bricklaying. We were trying to turn out a certain kind of workman, and we did that. We did it to such an extent that after a year and a half he worked out his liberty. We had power to recall him to the reformatory inside of five years if he did not behave

himself. With this string to him he went out. He wrote back to me: "I am getting $2 a day on the wall, and if 'Tom McCarthy' is ready to come out, I can get him a job. I have served several days in solitary, but here I am, and many thanks to you." In the morning he was in productive labor; he worked in the shoe shop pegging shoes on the contract system. In the afternoon he was put into the trade school, working on the purely technical part of the trade. An instructor was right there and told him whatever he could. Then in the evening he was put into the common school for two hours. He was taught the old-fashioned three R's. I merely state this to show that there is a wonderful demand even in that element of society to teach them the trades, and there is a probable defect in our public education along that line. As one man said, "When we teach no trades, we teach highway robbery." Therefore I can see very easily that there is a great demand for instruction in the trades. I have seen enough of it to feel and know that Professor Higgins has touched the keynote. If there is a demand for half-day schools for these men, then certainly there is a great demand for a similar but better for the great numbers of honest, faithful, and ambitious young American mechanics.

*Professor Higgins.**—I would like again to emphasize what I have already explained, that the discussion of this subject, the consideration of it, does not in any sense depreciate the present technical school or the engineering college or the professor of engineering or the consulting engineer. That I have made very plain in the paper to which I respectfully invite your attention; and furthermore, I would like to have it understood that my interest in the subject centres entirely upon the question of whether or not American mechanical supremacy shall be maintained through the proper education of American boys.

Whatever success we ascribe to the present methods of technical education, I am confident that all who will study the subject will admit that something else is demanded: a system that will reach the greater number of our sons who should become working mechanics (this greater number can be reached by the proposed half-time school); a system that is recommended and urged because it will not conflict with present good working systems, because it will not duplicate the present common-

* Author's closure, under the Rules.

from all walks in life; they are apprentice boys and journeymen, superintendents and draughtsmen; and of 900 students who thus come to us, many are occupying positions of trust with lucrative incomes, who come for special work. One man who has not had the work on the milling machine with which he is anxious to become acquainted comes and expects to get the best instruction possible in milling-machine work. Another one perhaps is after lathe work; others are there for tool-tempering, tool-dressing, foundry work, mechanics, pneumatics, drawing, electrical or mechanical laboratory testing. The effect of this on the instructors, who are also with the undergraduates of our regular engineering course, is to stimulate them to such endeavor as is necessary to bring themselves to the very highest proficiency they are capable of reaching. The constant contact of the teacher with students who know much less is apt to cause him to let slip away that which he has known, and keep that sort of knowledge which he finds necessary to impart to those knowing a great deal less. If by some method such as the one that I have just mentioned, but which I understand is impracticable in all cases, the instructor is brought daily, or at least frequently, in contact with journeymen and engineers, who are nearly as skilled in some, and in many respects more skilled than he is, the standard of the undergraduate student could be raised to a remarkable extent. The sifting process, or rather the reverse, that Professor Higgins mentioned, we find possible in students who come to us for this fragmental work in the evening schools; but those who are ambitious, and lack the fundamental training, find that it is extremely difficult, and likely to take them until old age before they accomplish the entire ground which they wish to cover. Many of these shift into the regular engineering course, and, as might be expected, among them are some of the best material that we have.

Mr. E. B. Johnston.—I would like to ask Mr. Higgins if it is implied that one-half of this schooling should be given in actual shop practice, and the other half in the school? If that is the fact, I think the sooner the society takes some cognizance of it the better. Two or three days ago a young man came to me and applied for a position as apprentice. I saw some of his drawing. It was crude, and in a way very amateurish. I gave him some of our work as a sample, and told him to take it and see what he could do. He returned this morning and showed

No. 965.*

TOPICAL DISCUSSIONS AND NOTES OF EXPERIENCE.

No. 144.—Protection of Penstocks from Corrosion.

Mr. H. deB. Parsons—It has occurred to me that it would be of interest to the members if information could be elicited as to the most satisfactory steps to be taken to preserve the metal feeder pipes and cases of turbine water-wheels.

There is an increasing demand for the utilization of water-powers, and it frequently happens that such problems will involve the bringing of the water under a considerable head through a pipe from the foot or base of a masonry dam to the power house. In connecting this steel or other plate-metal penstock to the face of the dam, it is usual to embed a metallic flanged ring or extension of the penstock proper, either part way into the masonry or else to carry such penstock clear through to the upper face. In either case, this penstock will be embedded in the masonry under water and difficult to inspect or replace; and will furthermore be exposed to the corrosive action of such water, as well as to the erosive action which may result from the movement of grit or sediment carried forward by the flow of the water.

What is the best material for coating this penstock both outside and inside with a view of prolonging its life under the conditions of its exposure? Can it be done with any known form of paint, or is the only safeguard some form of the methods which have been proposed for a coating or enamelling, which shall be a metallic oxide in such union with the metal as to be in effect part of it?

Mr. D. J. Lewis.—While at the Merrimack Manufacturing Com-

* Presented at the Cincinnati, Ohio, meeting (May, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXI. of the *Transactions*.

pany, of Lowell, Mass., I had a little experience with a penstock which was put in about 1847. About 1893 I took charge of the motive-power department of this corporation with the view of fixing it up and bringing it up to date. It was in November, after the canals were put on for the winter, and we put in a new wheel, and while we were working at the wheel I examined one of the old penstocks which had been put in by Colonel Francis in 1847, and found that barnacles had been accumulating all over the surface, some about an inch and a half high and about two inches in diameter. I went to work on what I could of it during the winter, but in the spring, after the canal was drawn off, having had considerable marine experience in shipyards, I attempted to see what I could do with cleaning. I scraped off the barnacles from one end to the other. I noticed that quite a number of them had pitted the pipe to as deep as $\frac{3}{16}$ of an inch. To get it thoroughly clean took me about six weeks; we had to do all the work on Sunday. They drew the canal off at five o'clock Saturday afternoon, and put it on at five o'clock on Sunday. During the time I was overhauling vessels in repairing a lot of English ships I came across a paint that the English engineers use for painting their bulkheads and also their coal bunkers. I thought I would try it on the penstocks. I sent for a barrel of this paint and coated the penstock all over. The first question I had to solve was how to get the penstock dry. It was about 8 feet in diameter and about 75 feet long. After conferring with my men, I decided to build wood fires in the bottom of it and see if we could not get the surface dry that way. It was a pretty heroic undertaking. The men had a bad time with it. But still we succeeded about eight o'clock Sunday morning in having the surface dry enough to put the paint on. We painted it with one coat, although it ought to have had two, and the water was turned on and it was used the rest of the summer and all winter. At the mouth of the penstock, where it connected to the canal, I placed a ring of red lead, ground in oil, one foot wide and the whole circumference of the penstock. One foot behind that I placed a ring of coal tar which I had thoroughly boiled, and then put on this enamel paint on the rest of the penstock. In the spring when the canal was drawn off I went in and examined the work. I found that the part that had been painted with this enamel paint was just as good as the day it was put on, but the red lead was badly scored and the same

a burden when he enters a real shop unless he bends to the unions.

Notwithstanding all this I do believe that there is a place for some such school as Mr. Higgins advocates, a school for the boy who is destined to be a mechanic, that he may be a better mechanic, and possibly become a foreman or superintendent.

I am still in doubt about the commercial side of it, especially in dull times, and can see no way to make such schools secure unless heavily endowed. As a part of the public school system a school of this kind would be too heavy a burden on the tax-payers, but if wealthy men can be induced to endow and manage schools which shall give to mechanics a thorough elementary education, and at the same time systematic shop training, the results will give a good interest on the investment.

Mr. John McGeorge.—This is a subject in which I am very deeply interested in two ways; first, as a father of boys growing up; second, as an employer of other boys coming from other homes. The first thought that comes to me through the reading of this paper is to commence with the last of the paper, this last paragraph. I think that we ourselves are very largely to blame for the condition of affairs at present existing. We have not put the position of the machinist on the high plane on which it ought to be put. We have rather looked down on the machinist as not being the equal of the draughtsman or the superintendent or the foreman. I remember in my young days being a candidate for the Whitworth scholarships. I had no theoretical training such as the boys get in these days. I was at work at fourteen, not going to half-time school, but working from 6 o'clock in the morning until 6 o'clock at night, and then going to evening school. During that time I competed for those scholarships for three years. I partly succeeded at last, but it was after a hard struggle. Whitworth's idea in establishing those scholarships was to make the chance of the apprentice who worked chiefly with his hands equal to that of the boy who was trained in the technical schools; but it was not so, not by a very long way. The students of technical schools had four times the advantage of the boy who worked with his hands. The first year I competed, the first thing that I noticed was that where the student only got two hours' examination in a certain branch of trade, the working boy had to take an eight-hour examination, and the two only counted

equal. Again, in comparing experiences with others coming from technical schools, I went over the relative marks to be obtained, and I found that Sir Joseph's intentions were completely subverted by those who had laid down the rules of the competition, giving the advantage entirely to the side of those who were going through the schools. Now there is where we are making our mistake. I am feeling it to-day. I have three boys. One has gone through the shops and got his schooling as I did, in his evenings' time. He now is the general manager of a very successful electric manufactory at twenty-five. The second one went through the draughting-room and is a very successful draughtsman. The third one is going through the shops now. But there is where I see the difference; he does not feel that he is the equal of the other two. He always feels that he is looked down upon because he has worked actually in the shops. It is useless to remind him that the first one went through the shops entirely and is now in a successful position. But there is the feeling of the American youth—and I am sorry to say that feeling is encouraged by people who are always pointing up—to get up higher. I am reminded somewhat in connection with this of a bit I read the other day, the comment of an old miner. He said that he had been thinking a good deal about low-grade ores. The prospectors were constantly going about seeking for rich strikes, seeking for high-grade ores that would bring in fortunes in a day, while the Chinamen and other steady people would go and take their leavings and work out not merely comfortable livings, but fortunes, through grinding steadily at the low-grade ores. It seems to me it is just like that in our schools; our students do not know what the low-grade ores are worth. They are encouraged to go on to the high-grade ores, high positions, positions of superintendent, just as high as they can go, and with the big salaries. They do not care to go on with moderate salaries day after day, with steady work as machinists, and I think it depends on this society to discourage that idea that the machinist, the skilled machinist, is not worthy of the highest praise. I well remember Mr. Gladstone's remarks, addressing some workingmen, when he tried to point out this very thing to them, showing that they were doing as much for the world, doing as much for themselves, and doing as much in every way as could be expected of them by working to the best of their ability at the trade they were

in. Let me just tell you another feature of that same thing. I noticed in Mr. Higgins's remarks a sentence about trying to put the entire class of students to a plane for which they are not fitted. That was not the language, but that is what it meant. Are we not making a mistake there? We take large classes of students and give them all the same treatment, and try to raise them to a mountain height that they cannot reach. When we do that we simply take a lot of men who never will be successful as leaders, who never will be real engineers, and spoil them for positions which they could fill, and fill well. Should we not encourage the raising of the standards of admission to these classes, and do a good deal more weeding out? I have in my mind now some young men of my acquaintance who have gone through high school and are about going to technical schools. They do not recognize their limitations. They never, so far as human foresight can see, will make the men they suppose they will. If they would stick steadily to some other so-called lower forms of work—a term I do not acknowledge—but to some other class of work, there they can make a success, leaving the apparently higher positions for others who can fill them, and this I think we can encourage by raising the standard of admission to those higher classes. I do not know whether I have made my meaning clear, but the sum and substance of the whole thing is: let the American youth forego the gambling spirit—I can only put it on that score—for wishing to make fortunes in a day, in other words, wishing to get something for nothing, to make rich strikes in place of steady work.

Mr. George I. Rockwood.—The first paper by Mr. Higgins I have read with some care, but this second paper I have not had an opportunity to examine so thoroughly, and may not, therefore, do him full justice. In so far as Mr. Higgins's ideas relate to the training of foremen and machinists, and of superintendents possibly, I think I am heartily in sympathy with him, without being able to defend my sympathy on precisely the same logical grounds that he puts forward. I must say, however, that Mr. Higgins's paper is not to be treated in any small or Philistine spirit. There can be no man in this country or in the world who has any greater claim upon our attention in regard to this subject or any greater claim to know whereof he speaks than Mr. Higgins. He, himself, is a successful manufacturer. He is also a successful instructor of youth—a rare

he was appointed in 1859 superintendent and member of the firm of Chubbuck & Campbell, with which firm he had served his apprenticeship, the firm then becoming Campbell, Whittier & Company. In 1874 the Whittier Machine Company was incorporated, Mr. Whittier becoming its president, which office he held until the time of his death. Mr. Whittier was a member of the Massachusetts Charitable Mechanic Association, the Boston Art Club, New England Historical and Genealogical Society, and the Massachusetts Horticultural Society, being greatly interested in horticulture, especially in fruit raising in Florida. He was one of the vice-presidents of the Eliot Five Cent Savings Bank, a trustee of Tufts College and Dean Academy, and in 1894 was elected to the Massachusetts Senate, where he served as chairman of the Committee on Manufacture. Mr. Whittier joined the Society at the Chicago meeting of May, 1886. In 1855 he married Miss Eliza Isabel. His death occurred at his home in Roxbury, Mass., on August 28, 1899.

HORACE S. SMITH.

Mr. Smith was born in Dunstable, N. H., in 1826, and the early years of his life were passed in the service of various railroads, both East and West, in the operating and mechanical departments. He rose gradually to positions of responsibility until he became master mechanic of the Chicago and Alton Railway at Bloomington, Ill. In 1857 he was in charge of the rolling stock and bridges of the V. & C. & N. & W. Ry., and in 1862 he was appointed superintendent of machinery and rolling stock on the Vermont and Massachusetts Railway, which position he held until 1865, when he became master mechanic on the C. A. & St. L. R. R., resigning this position in 1872 to accept the position of superintendent of machinery on the St. L., K. & N. Ry., becoming general superintendent of the Joliet Steel Works in 1874, and undertaking the great task of placing a run-down plant in good condition. Though at that time he had absolutely no experience in either rolling-mill or steel-works practice, he was most successful in this work, and when the company was reorganized in 1879, as the Joliet Steel Company, he had brought the works up to such a degree of efficiency that he was retained as general superintendent and held that position until the company was merged into the Illinois Steel Company in 1889. Mr. Smith introduced many improvements in the plant,

which were often of a radical character, his greatest professional triumph having probably been the development of intricate automatic machinery for rolling rails and billets, which greatly increased the capacity of a train of rolls and dispensed with much expensive labor, and it was due to its employment at Joliet that that plant leaped to the front as a rail producer. These improvements in slightly modified form are now in use in most of the large rail mills of this country. He also assisted William Garrett in the development of the rod mill and was also connected with the Fox Pressed Steel Company, being one of the leading officials of that company when it established works at Joliet. Shortly after the organization of the Illinois Steel Company he was appointed to a position involving the general oversight of all the company's several plants, and removed to Chicago. Subsequently he became a director and second vice-president of the company, which office he retained until he retired from active business in 1895.

One of Mr. Smith's sterling qualities was his admirable treatment of his workmen, and he ever maintained toward them an attitude of even-handed fairness and regard for their rights, and was accordingly respected, trusted, and beloved by all his men. He was one of the promoters and trustees of the Steel Works Club at Joliet, and believed thoroughly in the principle of a large company becoming interested in the personal welfare of its employees, and that the expenditure even of a considerable amount of money for their pleasure and mental improvement was a wise step. He connected himself with the Society in May, 1881, at the Hartford meeting, and served as a vice-president during 1886–88. During the latter years of his life he was consulting engineer of the Illinois Steel Company, with his headquarters at Chicago, and held this position at the time of his death, October 17, 1899, being buried at Joliet, where so much of his life had been spent.

EDWARD L. DENT.

Mr. Dent was born at Georgetown, D. C., July 5, 1861, and received his education at the Columbian University, Washington, D. C., and at Stevens Institute of Technology, graduating in the class of 1884. In 1885 he commenced the erection of a very complete plant for the manufacture of structural iron work,

of which plant he was senior partner and engineer, the business being conducted under the firm name of Edward L. Dent & Company, which business was continued until 1896. Mr. Dent was then connected with the Berlin Iron Bridge Company of East Berlin, Conn., with Morris Tasker, and afterwards with the Westinghouse Company, at East Pittsburg, Pa., with which company he was connected at the time of his death, which occurred at his residence in Wilkinsburg, Pa., October 19, 1899.

W. F. DURFEE.

Mr. William Franklin Durfee was born in New Bedford, Mass., in 1835. In 1853, or before he was of age, he became an engineer and architect in his native town, after a course at the Lawrence Scientific School of Harvard University.

In 1861 he served in the State legislature, and during the period of the Civil War he designed a gun for naval use. His greatest claim, however, for recognition as an engineer and specialist was the outcome of his removal to the Lake Superior district in 1862, when he undertook to test the suitability of certain ores of that district for the manufacture of steel, by a process invented by the late William Kelley. Mr. Durfee was invited, in June of that year, to design and superintend the construction and working of the necessary machinery and apparatus to test on a large scale the merits of the Kelley process. These works were erected at Wyandot, in connection with the buildings of the Eureka Furnace, some ten miles below Detroit, at the instance of Capt. E B. Ward of the latter city. It is probable that up to June of that year no citizen of the United States had seen the inside of a works where steel was made by the apparatus and process invented by Sir Henry Bessemer, with the possible exception of the late Z. S. Durfee, who at that time was in England, and who was a cousin of Mr. W. F. Durfee. Mr. Durfee described the features of this experimental steel works in a paper which he presented before the Society at its New York meeting in 1884, and it was published as paper No. 154 of the Society *Transactions*. This experience resulted in the rolling of several ingots of steel, from which, on May 25, 1865, were rolled the first steel rails produced in this country. Mr. Durfee also established, in connection with his experimental plant, the first steel-works analytical laboratory which was built in the

United States. This achievement of Mr. Durfee made him in many ways a memorable figure in American progress, and was enough to have established his eminence as an engineer. In 1876 he was chosen as one of the judges for machine tools for working in wood, iron, and stone, in connection with the Philadelphia Centennial Exhibition, at which time he received a medal. Later he built, at Ansonia, Conn., the first gas furnace for refining copper, and remained for many years in close relation to the development of the Wheeler & Wilson Company of Bridgeport.

It was about this time that he became general manager of a company controlling patents for the production of castings in wrought iron, and did much towards the development of a machine of notable character for the production of horseshoe nails by machinery. On leaving Bridgeport he connected himself with the machinery plant of the Pennsylvania Drill Company at Birdsboro, Pa., and afterwards moved to Staten Island to become shop superintendent for the C. W. Hunt Company. At the conclusion of this engagement he entered the general practice of expert before the courts, in patent and similar cases, and kept up his indefatigable labors as a student, reader, and writer.

A short time before his death he showed signs of failing health, which ended in acute melancholia, which was terminated by his death at Middletown, N. Y., November 14, 1899.

Mr. Durfee will be remembered as a charter member of the Society, and served it in office twice. He was specially well equipped by reason of an almost encyclopædic knowledge of the past history and achievement in many lines of engineering, and had accumulated during his busy life a library particularly rich in mechanical antiquities. It is not usual that we find combined such talent for research with the wide practical experience which made him an exceptionally well-qualified designer. It was his wish that on his death his library should become the property of the American Society of Mechanical Engineers, and the arrangement for the transfer from his Staten Island home was in progress when his death was announced.

During his residence in Pennsylvania he had become a member of the Franklin Institute of Philadelphia, and he was also a member of the Iron and Steel Institute of Great Britain, before which body he had presented contributions. He was a very regular attendant at the conventions of the Society and a frequent contributor to its discussions.

LOUIS S. WRIGHT.

Mr. Wright was born at Philadelphia, Pa., August 6, 1859, and received his early education in the public schools of his native town with instruction at the Franklin Institute, and afterwards served three years' apprenticeship in the machine shop of Wm. Sellers & Company. After this he was connected with the Stow Flexible Shaft Company's shop at Philadelphia as their general foreman, and then connected himself with the Midvale Steel Company, and while there was engaged on work in connection with the adjustment of wages on the "piece rate" work system and made a specialty of systematizing shop methods. In 1889 he became superintendent of the Link-Belt Machinery Company, continuing as such until January 31, 1891, some of the most important work done by that company being carried on under his direction, and the organization inaugurated there by him has been continued without material alterations until the present time. In January, 1891, severing his connection with that company, he was appointed general superintendent of R. D. Wood & Company's works at Camden, N. J., which position he retained for several years until he had to relinquish it on account of ill health. Advised by his physician to secure outdoor employment, he took charge of the then newly constructed trolley lines in Pottsville, Pa., where he won the love and respect of a host of friends by his uniform kindness and manifest ability. While employed at this work his health became much impaired, and to the regret of his friends it was discovered that he was suffering with locomotor ataxia. He made a most heroic struggle to continue an active life, but finally had to succumb, and for the last two years of his life he was physically incapacitated, but his mentality endured to the last.

His death occurred on December 29, 1899. Mr. Wright connected himself with the Society at the Cincinnati meeting in May, 1890.

JOHN L. WILKINSON.

Mr. Wilkinson was born at Gorton, England, October 9, 1842, and served his apprenticeship with the Manchester, Sheffield, and Lincolnshire Railway Company during 1856-63. In the latter year he came to America and located in New York, remaining there until 1875, during which time he was connected in

various positions with a number of well-known iron works; he then returned to England and until 1875 he was connected with the railway with which he had served his apprenticeship and with the Crabtree Engineering Works. After this he was connected with the New York Steam Company and as chief engineer of the plants in a number of large buildings in New York City and State, and for a time was chief engineer of the Criminal Court Building, at New York, N. Y. His connection with the Society dated from the May meeting at Hartford, Conn., in 1880.

His death occurred January 16, 1900.

JOSEPH P. MULLIN.

Mr. Mullin was born at Waterdown, Ontario, Canada, 1854, and served his apprenticeship with engineering firms at Hamilton, Ohio, and for a time was connected with the Beckett Foundry and Machine Company, of Arlington, N. J., and N. B. Crahing & Company of Jersey City, N. J. He joined the Society at the New York meeting in December, 1894, at which time he was the general manager of the Beckett Foundry and Machine Works, which position he retained until that company went out of business. Severing his connection with that company, he associated himself with Mr. James Fogarty, engaged in the manufacture of an improved steel gear wheel, made under his patent, for use on street cars driven by electric motors, the object being to supply a wheel in which the teeth were cut on a ring which could be removed from the wheel when worn, without disturbing the wheel centre or the motor, and was so engaged at the time of his death from pneumonia at Arlington, N. J., on January 29, 1900.

WILLIAM E. WARD.

Mr. Ward was born in Indiana in April, 1821, and removed to Port Chester, N. Y., in 1845, engaging in the manufacture of wood screws with Elwood Burdsall and Isaac D. Russell under the firm name of the Union Screw Company. After the company had been in operation for a short time their business was brought to a standstill by the introduction of a gimlet-pointed screw. This newly invented screw, introduced by the New

England Screw Company, was a severe blow to Mr. Ward's firm, but his inventive mind solved the difficulties and opened up a channel that led to the building up to its present proportions of the firm of Russell, Burdsall & Ward. This was the invention of automatic machines for manufacturing stove bolts, plough bolts, and carriage bolts, and Mr. Ward can be justly said to have been the pioneer of the bolt and nut business. In 1852 he married Miss Tacie Lukens, who survives, together with one son and one daughter. He was a member of the Society of Friends, a charter member of this Society, and a member of the American Society for the Advancement of Science. Besides being president of the firm of Russell, Burdsall & Ward he was president of the Port Chester Bolt and Nut Company, and a director of the First National Bank of Port Chester. The simple ceremonies of the Society of Friends, of which he had been a consistent member during his life, were observed at his funeral, at which were gathered many who fill prominent positions in mechanical and business circles throughout the country. The date of his death was March 2, 1900.

HERBERT GUERNSEY GEER.

Mr. Geer was born at Ogdensburg, N. Y., March 13, 1869, the family afterwards moving to Potsdam, N. Y., where he received his education at the Normal College, graduating in 1887, and entering Cornell University in the fall of that year. He remained at Cornell until 1891, when he went West and was engaged in work on the Union Pacific and Southern Pacific Railroads, returning to Cornell in 1893 and taking his degree as M. E. For the next six years he was assistant mechanical engineer in the electrical engineering department of Johns Hopkins University. He joined the Maryland Naval Reserves upon their organization in 1893, and was successively chief engineer, lieutenant, and signal officer, and acting lieutenant-commander. In addition to his university work Mr. Geer was engaged as a consulting electrical engineer and steam expert in Maryland and Virginia. On March 4, 1898, Mr. Geer married Miss Sarah M. Macneal of Baltimore. His final sickness was of several months' duration, and with the hope of improving his health he went to Saranac in the summer of 1899, where he gained so materially that it was thought his recovery was

assured. His health failed, however, and he died at his home in Baltimore on March 7, 1900. Mr. Geer joined the Society at the Washington meeting in May, 1899.

ADDISON C. RAND.

Mr. Rand was born at Westfield, Mass., in 1841, and for many years was connected with his father's machine shop and works, afterwards having charge of the factory. He then engaged in the introduction of dynamite east of the Rocky Mountains, followed by four or five years' experimental work in connection with rock drills and air compressors. Mr. Rand was president of the Rand Drill Company and treasurer of the Kendrick Powder Company, which positions he filled until the time of his death, which occurred March 9, 1900. He connected himself with the Society at the New York meeting of 1891.

WILLARD B. ROBERTS.

Mr. Roberts was born at Laporte, Ind., in 1848, and received his technical education at the Sheffield Scientific School of Yale University. In 1863 he connected himself with the Bureau of Steam Engineering of the Navy Department at Washington, and remained there several years. During the years 1875 to 1877 he was chief draughtsman for manufacturing firms at Hartford, Conn., and Indianapolis, Ind. In 1879 Mr. Roberts became superintendent of the St. Paul Foundry and Manufacturing Company at St. Paul, Minn., and in 1890 was appointed assistant engineer of the Great Northern Railway at St. Paul, and from that date until 1893 he was connected with the road and coal companies controlled by it.

Mr. Roberts joined the Society in 1880, and continued as an active member until 1884, when, at that time, as he was no longer engaged in the practice of his profession, he allowed his membership to lapse. On returning to the practice of his profession, however, in 1898, he again applied for membership and was reëlected a member at the Niagara Falls meeting of that year. At that time Mr. Roberts was mechanical engineer of the Q. and C. Company, manufacturers of railway specialties, of Chicago, and at the time of his death, which occurred April 9, 1900, he was general manager of the Northwestern Gold and Platinum Dredging Company, located at Chicago.

SALVADÒR POTIS.

Mr. Potis was born November 16, 1860, at La Guayra, Venezuela, S. A., and was educated at the Queen's Collegiate School, Port of Spain, Trinidad, B. W. I., and at the Bolivar College at same place, and for three years after leaving college was engaged in mining work at points in Venezuela. He then entered the works of the Continental Iron Works at Brooklyn, N. Y., and served an apprenticeship of eighteen months there. Following this he was connected with other engineering companies in this country, and at the time of the Richmond meeting, in November, 1890, when he joined the Society, he was assistant chief draughtsman of the United States Construction Company of Chicago. He was a member of the Technical Club of Chicago, and at the time of his death, April 17, 1900, he was practising his profession in that city.

J. G. ARNOLD MEYER.

Mr. J. G. A. Meyer was born in Berlin, Germany, 1841, but while he was quite young his father moved to England, where he was educated and served an apprenticeship as a millwright. When he was about twenty years of age he came to Canada, and was there employed by the Grand Trunk Railway; afterwards removing to Boston, where he was employed by several firms. Later he held various positions in New York City, being for a time connected with the Delamater Iron Works, and also under General McClellan, when he was building docks for the city, and by whom he was held in high esteem. He was head draughtsman of the Grant Locomotive Works at Paterson, N. J., for a number of years, and during this time he became a contributor to the columns of the *American Machinist*, and connected himself with that paper as associate editor in October, 1887, which connection he maintained until 1895. Mr. Meyer was an unsurpassed draughtsman, and his specialty in technical work was in dealing with the problems, and in describing the methods, of the draughtsman.

He was the author of a book on "Modern Locomotive Construction," and shortly before his death had finished a work on "Machine Drawing and Machine Design," which was not as

yet published at the time of his death. He suffered from a stroke of paralysis in October, 1899, at which time he was manager of the Arnold Publishing House of New York, and on July 16, 1900, he died from apoplexy. His membership in the Society dated from the Washington meeting of 1887.

INDEX TO VOLUME XXI.

NOTE.

1. For authors of papers and for the names of debaters upon them, SMALL CAPS are used.

2. *Italic type* is used for the full titles of papers. Cross references to the subject of a paper which may not be its exact title are in roman type, as are the titles under the caption of the author's name.

3. The Society is not responsible as a body for the statements of fact or opinion in its papers and discussions.

PAGE

Air pumps, performance of 1101
ALDEN, GEO. I., disc., education of machinists, foremen, and mechanical engineers 729
ALDRICH, WM. S., Systems and efficiency of electric transmission in factories and mills 912
ALLEN, J. R., A test of a fifteen-million high-duty pumping engine at Grand Rapids, Mich 1018
ALLISON, ROBT., disc., the automobile wagon for heavy duty 868
Alternating current, transmission in factories 922
Analysis of coal 65
Analysis of Ohio natural gas 963
Automobile wagon for heavy duty, ARTHUR HERSCHMANN 844

BALDWIN, S. W., disc., education of machinists, foremen, and mechanical engineers 721
BALL, BERT C., cylinder proportions for compound and triple-expansion engines 1002
Balls, strength of 351
BARTH, CARL G., disc., design of speed cones 840
BASFORD, G. M., disc., friction tests of a locomotive slide valve 250
BENJAMIN, C. H., Friction of steam packings, 292; disc, education of machinists and mechanical engineers, 1135; disc., efficiency of electric transmission in factories and mills 933
Berthier method of coal calorimetry, C. V. KERR 304
Bitumastic enamel paint 1156
Blue-print machine, curved glass 586
BOLTON, R. P., disc., mechanical equipment of Boston Terminal Station 570
BOYER, FRANCIS H., disc., a broken fly wheel and how repaired 270
Brakes in automobile practice 847
Broken fly wheel and how it was repaired, JAMES MCBRIDE 262
BRYAN, WM. H., disc., revision of boiler code 121
BUMPUS, E. C., disc., on the value of a horse-power 612

Calorimeters 73
Carbonic acid for automobile wagon 849
CARPENTER, R. C., disc., revision of boiler code 127

PAGE
Carrying capacities of motor wagons 860
CARY, A. A., disc., water-softening plant 883
Central station for automobile 857
Central-station heating 937
CHAMBERLAIN, PAUL M., A metal dynamograph, 578; curved glass blue-print machine, 586; disc., education of machinists and mechanical engineers, 1141; disc., the automobile wagon for heavy duty 868
CHARTER, JAS. A., disc., gas-engine hot tube 1000
Chimney gases 91
Clark's process for softening water 875
Coal calorimetry, Berthier method 304
Colors of heated steel corresponding to different degrees of temperature, MAUNSEL WHITE and F. W. TAYLOR 627
Committee on revision of Society code for conducting steam-boiler trials. 34
Compound engines, cylinder proportions for 1002
Compressed air for automobile wagons 849
Compression of liquids by high hydrostatic pressures 439
Compression and liquefaction of gases, ARTHUR L. RICE 156
Construction of entropy temperature diagram from indicator card 275
COOLEY, M. E., Test of a fifteen-million high-duty pumping engine at Grand Rapids, Mich 1018
Corrosion of penstocks 1154
Curved glass blue-print machine, PAUL MELLEN CHAMBERLAIN 586
Cylinder proportions for compound and triple expansion engines, BERT C. BALL 1002

DAVIS, CHAS. E., disc., education of machinists and mechanical engineers. 1146
Dent, Edward L., memorial notice of 1160
Design of speed cones, JAS. J. GUEST 832
Dewar liquid air apparatus 160
Direct-current transmission in factories 920
Draft gauge 87
DU BRUL, ERNEST F., disc., the automobile wagon for heavy duty 871
Durfee, W. F., Library of, 8; Memorial notice of 1161
Dynamograph, a metal 578

Eames draft gauge 123
EDDY, HENRY T., A new graphical method of constructing the entropy temperature diagram of a gas or oil engine from its indicator card 275
Education of machinists, foremen, and mechanical engineers, M. P. HIGGINS 646, 1114
Efficiency of boiler 78
Efficiency test of a one hundred and twenty-five horse-power gas engine, C. H. ROBERTSON 396
Electric automobile wagon 848
Electric generators, standardization of 10
Electric transmission in factories 912
EMORY, F. L., disc., education of machinists and mechanical engineers, 1151; disc., gas-engine hot tube, 994; disc., test of a fifteen-million high-duty pumping engine 1112

PAGE
Engineering in the United States Navy, GEO. W. MELVILLE..... 139
Entropy temperature diagram of a gas or oil engine..... 275
Expansion of steam mains..... 947
Experiments on using gasoline gas for boiler heating, HERMAN POOLE..... 172
Explosive motors for automobiles..... 849

Flanges, committee on..... 29
Flanges, standards for..... 29
Fly wheels, design of..... 317
Fly wheels, how repaired..... 262
FOSTER, E. H., Pumping-engine test with superheated steam..... 788
Friction in steam mains..... 947
Friction of pump valves..... 1103
Friction of steam packings, CHAS. H. BENJAMIN 292
Friction tests of a locomotive slide valve, F. C. WAGNER..... 242
FRITH, A. J., A note on fly-wheel design, 317 ; disc., entropy temperature diagram of a gas or oil engine..... 285
FRITZ, JOHN, disc., education of machinists, foremen, and mechanical engineers..... 727
Fulton memorial, committee on..... 19

Gas engine, efficiency test of..... 396
Gas-engine hot tube as an ignition-timing device, W. T. MAGRUDER..... 961
Gas motors for automobiles..... 849
Gases, compression and liquefaction of..... 156
Gasoline gas for boiler heating, experiments on..... 172
Gasoline odors in automobiles 851
Geer, Herbert G., memorial notice of..... 1165
GOLDSMITH, N. O., Water-softening plant at the Lorain Steel Company's blast furnaces 874
GOSS, W. F. M., Test of the Snow pumping engine at the Riverside Station of the Indianapolis Water Company..... 793
Grand Rapids water works, pumping-engine test 1018
Greacen makes compound engine of large cylinder ratio..... 1009
Grease trap..... 945
GRIFFIN, CHAS L., disc., education of machinists, foremen, and mechanical engineers..... 753
GUEST, JAS. J., On the design of speed cones. A new formula..... 832

HAINES, H. S., disc., education of machinists, foremen, and mechanical engineers 715
HALE, R. S., disc., revision of boiler code..... 112
HALSEY, F. A., disc , education of machinists, foremen, and mechanical engineers, 732 ; disc., friction tests of a locomotive slide valve, 251; test of a fifteen-million high-duty pumping engine..... 1112
HARRIS, J. F. W., Strength of steel balls..... 351
Heated steel, color temperatures of..... 627
Heating by hot water..... 937
HEISLER, CHAS. L., disc., Snow pumping engine of the Indianapolis Water Company..... 824

PAGE

HENNING, G. C., disc., a new form of pressure gauge, 448; disc., a note on fly-wheel design, 323; disc., color temperatures of heated steel, 637; disc., strength of steel balls 359
HERSCHMANN, ARTHUR, the automobile wagon for heavy duty 844
HIBBARD, H. WADE, disc., education of machinists, foremen, and mechanical engineers 760
HIGGINS, MILTON P., education of machinists, foremen, and mechanical engineers, 646; disc., color temperatures of heated steel, 643; education of machinists, foremen, and mechanical engineers 1114
High hydrostatic pressures and their application to compressing liquids; a new form of pressure gauge, FRANCIS E. STILLMAN 439
Hollingsworth, Sumner, memorial notice of 1158
Horse-power, value of 590
Hot tube of gas-engine as an ignition-timing device 961
Hot-water heating from a central station, H. T. YARYAN 937
HOWE, H. M., disc., color temperatures of heated steel 629
HUNT, ROBT. W., disc., education of machinists, foremen, and mechanical engineers 725
HUTTON, F. R., disc., education of machinists, foremen, and mechanical engineers 692
Hydraulic transmission in factories 914

Ignition in gas engines 967
Ignition timing device, the gas-engine hot tube 961
Impact, W. J. KEEP 369
Indianapolis pumping-engine test 793
Induction motors in factories 923

Jacket temperature in gas engine 978
JACOBUS, D. S., disc., a new form of pressure gauge, 447; disc., education of machinists, foremen, and mechanical engineers, 739; disc., revision of boiler code, 119; disc., test of two ten-million-gallon pumping engines. 345
Jewett, ——, disc, hot-water heating from a central station 953
JONES, DAVID P., disc., revision of boiler code 136
JOHNSON, J. B., disc., education of machinists, foremen, and mechanical engineers, 752; disc, impact 390
JOHNSTON, E. B., disc., education of machinists, foremen, and mechanical engineers 1143
Junior Committee, report of, May, 1900 779

KEEP, W. J., impact 369
KENT, WM., disc., a note on fly-wheel design, 324; disc., education of machinists, foremen, and mechanical engineers, 1142; disc, mechanical equipment of New South Station, Boston, 566; disc., value of a horse-power 617
KERR, WALTER C., mechanical equipment of the New South Station, Boston, Mass 451
KERR, C. V., the Berthier method of coal calorimetry 304
KINEALY, J. H., disc., the Berthier method of coal calorimetry 312

LAIRD, JNO. A., test of two ten-million-gallon pumping engines at the Baden Pumping Station, St. Louis Water Works 327

PAGE

LANZ, GAETANO, disc., a broken fly-wheel and how repaired, 570; disc., a note on fly-wheel design 323
Leakage of high-duty pump 1042
LEWIS, D. J., disc., protection of penstocks from corrosion 1154
LEWIS, WILFRED, disc., pressure in pipe due to stoppage of flowing liquid 258
Liquid air 162
LOCKWOOD, E. H., disc., design of speed cones 835
Locomotive slide valve, friction tests of 242
LODGE, WM., disc., education of machinists, foremen, and mechanical engineers 1145
LONGSTRETH, CHAS., disc., friction of steam packings 298
Lorain blast furnace water plant 874
LORENZ, WM. A., disc., education of machinists, foremen, and mechanical engineers 755

McBRIDE, JAS., a broken fly-wheel and how it was repaired 262
McFARLAND, WALTER M., disc., efficiency of electric transmission in factories and mills 928
McGEORGE, JOHN, disc., automobile wagon for heavy duty, 876; disc., efficiency of electric transmission in factories and mills, 931; disc., education of machinists, foremen, and mechanical engineers 1136
MAGRUDER, WM. T., the gas-engine hot tube as an ignition-timing device, 961; disc., an efficiency test of a gas engine, 432; disc., education of machinists, foremen, and mechanical engineers, 745; disc., friction tests of a locomotive slide valve, 248; disc., strength of steel balls, 361; disc., water-softening plant 890
MATTES, W. F., disc., hot-water heating from a central station 950
MATTICE, A. M., disc., steam engine at the end of the nineteenth century, 240; disc., test of two ten-million-gallon pumping engines 343
MAXWELL, JAS. R., disc., the automobile wagon for heavy duty 865
Mechanical equipment of the New South Station, Boston, Mass., WALTER C. KERR, ... 451
MEIER, E. D., disc., revision of boiler code 131
MELVILLE, GEO. W., Engineering in the United States Navy.—Its Personnel and Matériel, 139; disc., education of machinists, foremen, and mechanical engineers 685
MERRIMAN, M., disc., impact 389
Metal dynamograph, PAUL MELLEN CHAMBERLAIN 578
METCALF, WM., disc., color temperatures of heated steel 629
Meyer, J. G. Arnold, memorial notice of 1167
MILLER, F. J., disc., color temperatures of heated steel 634
Moisture in coal 63
Motors, efficiency of 917
Mullin, Jos. P., memorial notice of 1164
Multiple-cylinder engines, reheaters for 893

NAGLE, A. F., disc., a new form of pressure gauge 446
New graphical method of constructing the entropy temperature diagram of a gas or oil engine from its indicator card, HENRY T. EDDY 275
Note on fly-wheel design, A. J. FRITH 317

PAGE
Oil motors, for automobiles 849

Packings, friction of 292
PARSONS, WM. B., disc., education of machinists, foremen, and mechanical engineers 763
PARSONS, H. DE B., disc., protection of penstocks from corrosion, 1154; disc., value of a horse-power 614
PEABODY, E. H., disc., revision of boiler code 125
PEEK, GEO. M., pressure in pipe due to stoppage of flowing liquids 255
Penstocks, protection of 1154
PLATT, JOHN, disc., mechanical equipment of Boston Terminal Station 569
POOLE, HERMAN, experiments on using gasoline gas for boiler heating 172
PORTER, CHAS. T., disc., a note on fly-wheel design, 322; disc., steam engine at the end of the nineteenth century 231
Potis, Salvador, memorial notice of 1167
PRATT, C. R., disc., strength of steel balls 366
Pressure gauge, new form of 439
Pressure in pipe due to stoppage of flowing liquids, GEO. M. PEEK 255
Proceedings Cincinnati (XLIst) meeting 771
Proceedings New York (XLth) meeting 3
Proportions of cylinders of compound and triple-expansion engines 1002
Protection of penstocks from corrosion 1154
Pumping-engine test at Grand Rapids, Mich 1018
Pumping-engine test with superheated steam, E. H. FOSTER 788
Pumping engines, test of two ten-million-gallon, at Baden Pumping Station, St. Louis Water Works 327

Rand, A. C., memorial notice of 1166
RANDOLPH, L. S., disc., education of machinists, foremen, and mechanical engineers 761
RAYNAL, A. H., disc., a broken fly-wheel and how repaired, 273; disc., value of a horse-power 617
Reheaters in multiple-cylinder engines, R. H. THURSTON 893
Repairing a broken fly-wheel 262
Report of committee on boiler code, discussion 112
Report of committee on European trip, 1900 23
Report of committee on the revision of the Society code of 1885, relative to a standard method of conducting steam-boiler trials 34
Report of committee on flange standardization 29
Report of committee on Fulton memorial 19
Report of committee on standard sizes for electrical generators 776
RICHARDS, C. B., disc., education of machinists, foremen, and mechanical engineers 751
RICE, ARTHUR L., compression and liquefaction of gases 156
Ringelmann smoke chart 97
ROBERTS, E. W., disc., the gas-engine hot tube 998
Roberts, Willard B., memorial notice of 1166
ROBERTS, WM., disc., the automobile wagon for heavy duty 867

PAGE

ROBERTSON, C. H., efficiency test of a one hundred and twenty-five horse-power gas engine ... 396
ROCKWOOD, GEO. I., the value of a horse-power, 590; disc., education of machinists and mechanical engineers, 1138; disc., mechanical equipment of Boston Terminal Station, 565; disc., reheaters in multiple-cylinder engines ... 908
ROGERS, W. S., disc., education of machinists, foremen, and mechanical engineers ... 736
Rohrer, A. L., invites convention of 1901 ... 782
ROYSE, DANIEL, disc., hot-water heating from a central station ... 957
Rules for conducting boiler trials ... 38
RUUD, EDWIN, disc., an efficiency test of a gas engine ... 427

SANGSTER, WM., disc., a broken fly-wheel and how repaired ... 272
SANGUINETTI, P. A., disc., education of machinists, foremen, and mechanical engineers ... 754
SARGENT, C. E., disc., an efficiency test of a gas engine ... 430
SCHNEBLE, R. G., disc., the gas-engine hot tube ... 997
SCHUHMANN, GEO., disc., friction tests of a locomotive slide valve ... 249
Shafting efficiency in factories ... 916
SMART, R. A., disc., friction tests of a locomotive slide valve ... 246
Smith, Horace S., memorial notice of ... 1159
SMITH, OBERLIN, disc., color temperatures of heated steel, 638; disc., strength of steel balls ... 363
Snow pumping engine test ... 793
Solubility of lime in water ... 885
SORGE, A., Jr., water softening plant ... 887
South Station, Boston, mechanical equipment of ... 451
SOUTHER, H., disc., strength of steel balls, 367; disc., color temperatures of heated steel ... 642
SPANGLER, H. W., disc., revision of boiler code ... 116
Speed cones ... 832
Standard sizes for electrical generators ... 776
STANWOOD, J. B., presents report on standard sizes of electrical generators, 776; disc., steam-engine at the end of the Ninteenth Century ... 227
Steam-engine at the end of the Nineteenth Century, R. H. THURSTON ... 181
Steam packings, friction of ... 292
Steam wagons ... 855
Steel balls, strength of ... 351
STETSON, GEO. R., disc., color temperatures of heated steel ... 639
STILLMAN, FRANCIS H., a new form of pressure gauge ... 439
Strength of steel balls, J. F. W. HARRIS ... 351
Superheated steam, test ... 778
SUPLEE, H. H., disc., a broken fly-wheel and how repaired, 271; disc., a metal dynamograph, 584; disc., color temperatures of heated steel ... 641
Superheating in multiple-cylinder engines ... 907
SWEET, JNO. E., disc., a broken fly-wheel and how repaired, 269; disc., education of machinists, foremen, and mechanical engineers ... 719
Synchronous motors in factories ... 924

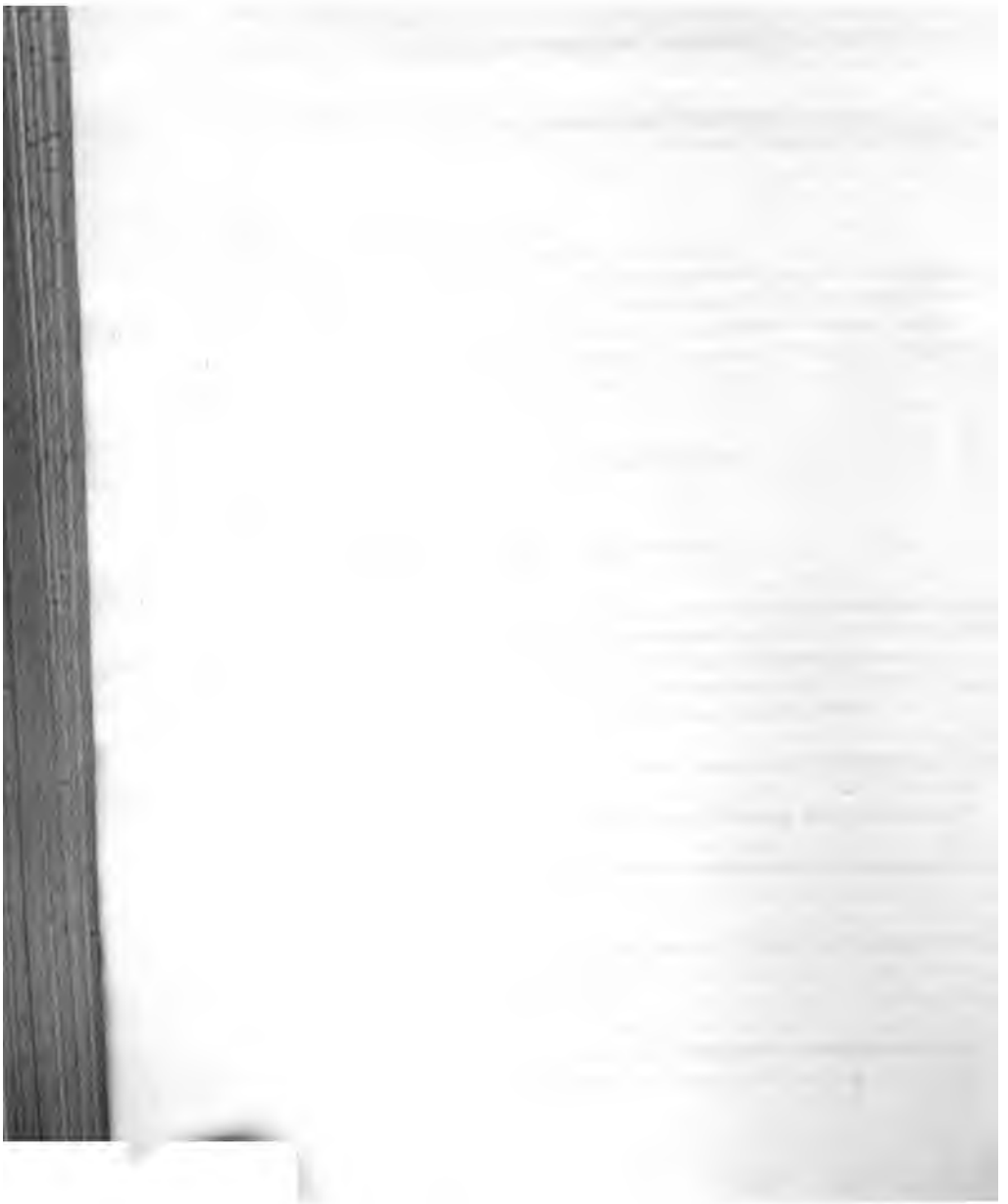
PAGE

Systems of efficiency of electric transmission in factories and mills, WM. S. ALDRICH 912

TAYLOR, F. W., and MAUNSEL WHITE, colors of heated steel corresponding to different degrees of temperature 627
Terminal at Boston, engineering of 451
Test of engine with superheated steam 788
Test of a fifteen-million high-duty pumping-engine at Grand Rapids, Mich., M. E. COOLEY 1018
Test of a one hundred and twenty-five horse-power gas engine, C. H. ROBERTSON 396
Test of two ten-million-gallon pumping-engines at the Baden Pumping Station; St. Louis Water Works, June, 1899, JNO. A. LAIRD 327
Test of the Snow pumping-engine at the Riverside Station of the Indianapolis Water Co., W. F. M. GOSS 793
Testing of automobiles 862
Tests of a locomotive slide valve 242
THOMAS, CHAS. W., disc., strength of steel balls 363
THURSTON, R. H., Reheaters in multiple-cylinder engines, 893; the steam-engine at the end of the Nineteenth Century, 181; disc., an efficiency test of a gas engine, 425; education of machinists, foremen, and mechanical engineers, 691; mechanical equipment of New South Station, 568; disc., value of a horse-power 621
Timing-device, the gas-engine hot tube 961
Tires for automobiles 853
Triple-expansion engines, cylinder proportions for 1092
Tripler liquid air apparatus 162

Value of a horse-power, GEORGE I. ROCKWOOD 590

WAGNER, FRANK C., a test of a fifteen-million high-duty pumping-engine at Grand Rapids, Mich., 1018; friction tests of a locomotive slide valve, 242; disc, test of a fifteen-million high-duty pumping-engine 1112
WALDRON, FREDK. A., disc., hot-water heating from a central station 949
WALLACE, ——, disc., hot-water heating from a central station 957
Ward, Wm. E., memorial notice of 1164
Water-softening plant at the Lorain Steel Company's blast furnaces, N. O. GOLDSMITH 874
WEIL, C. L., disc., education of machinists, foremen, and mechanical engineers 759
WESLEY, ——, disc., efficiency of electric transmission in factories and mills 932
Wheels for automobiles 853
WHITE, MAUNSEL, and F. W. TAYLOR, colors of heated steel corresponding to different degrees of temperature 627
Whittier, Charles, memorial notice of 1158
Wilkinson, John L., memorial notice of 1163
WILLIS, E. J., disc., efficiency of electric transmission in factories and mills, 932; disc., gas-engine hot tube 1000

PAGE
WILLISTON, A. L., disc., colored temperatures of heated steel, 636; disc., education of machinists, foremen, and mechanical engineers..... 728
WOODWARD, D. C., disc., efficiency of electric transmission in factories and mills..... 934
WOOLSON, O. C., disc., education of machinists, foremen, and mechanical engineers..... 757
Wright, Louis S., memorial notice of..... 1163

YARYAN, H. T., hot-water heating from a central station..... 937